AD34183

RESEARCH STUDY AND INVESTIGATION ON TELEVISION TECHNIQUES FOR ADVANCED RECONNAISSANCE SYSTEMS (U)

RADIO CORP OF AMERICA CAMDEN NJ

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PREFACE

This report is a supplement to the Final Report, Project MX-2226 ⑥ "Research Study and Investigation on Television Techniques for Advanced Reconnaissance Systems," dated October 9, 1957. The project is being performed by Defense Electronic Products of RCA for the Air Force under the direction of Wright Air Development Center. The contract number is AF33(616)2576. The present contract continues the work started on subcontract 52-63 of Contract Number AF33(038)6413. Work on the above contract was reported on in a final report dated 4/15/54.

The study deals with the feasibility, application and implementation of a television system to the problem of reconnaissance from an earth satellite. Because of the high cost of weight and space aboard such a satellite, every effort must be made to make the equipment light and compact. The power consumption should be kept at a minimum, not only because of weight requirements but also because of the difficulty of dissipating degrading heat. Reliability also is a major consideration since long, unattended life with a minimum of remotely controlled adjustments is a design requirement.

The purpose of this project was:

1. To continue studies evaluating the feasibility of a television system for this type of specialized advance reconnaissance.

2. To life test preliminary breadboards for evaluation of component and system reliability.

3. To evaluate alternate approaches to any of the problems where such seem to have a chance of fulfilling the requirements.

4. To construct certain research models where such would be useful in evaluating the problem.

5. To study the electronic implementation of the interpretation and dissemination of the information obtained by the reconnaissance system.

Studies of ~~were made in the individual fields of:~~

a. Optical Systems,
b. TV Camera
c. Video Recording (magnetic), and
d. TV Transmitters
e. Antenna Servo Systems
f. Kinescope Recording of photographic images are reported.
g. Information Presentation
h. Reliability Studies
i. Transistor Applicabilities

These studies were coordinated by preliminary systems examinations whenever deemed necessary so that the overall results would be mutually compatible.

The final report on this project reported in full on all the topics mentioned above except Optical Systems, Video Recording (magnetic) and Kinescope Recording, additional work on these being carried past the contract period. This report completes the reporting on these topics.

Defense Electronic Products (formerly Engineering Products Division) of RCA was the prime contractor for this project. The work was supplemented by subcontracts to the RCA Tube Division and to the RCA Laboratories Division.

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I. INTRODUCTION

This report represents the results obtained from a continuation of parts of an overall research and development study program carried out under contract number AF33(616)2576. The results contained herein serve to supplement the information given in the Final Report of this contract, Project MX-2226, Final Engineering Report, dated October 9, 1957.

A. Optics, Ground Imaging System

The delays experienced in obtaining the reflection prisms for the segmentation drums prevented the completion of the optical tests for inclusion in the final report. The results of the optical tests on the completed 38-inch focal length Schmidt cameras and the segmentation device are included in this supplement as well as the alignment procedures for all components of the system. Photographs taken with the completed unit are included. These show that the optical equipment performs as predicted.

B. Magnetic Video Recording System

At the end of the time period covered by the Final Report the status of some phases of the magnetic video recorder development were rather indecisive. During this supplementary period the FM recording system design was finalized and six channels completed. Complete circuit diagrams of the FM recording system including tape record and playback amplifiers are shown in this report. Each of the six FM channels provides excellent one megacycle video performance with no interchannel crosstalk. Tape handling techniques were improved to the extent that the maximum potential performance of the magnetic heads is achieved consistently and the information on six tracks on one-half inch tape can be added together without significant time difference errors resulting from tape skew. It is concluded that no system employing multiplexing within the tape system is feasible for the application. A parallel channel system employing a multiplicity of independently operating narrow band vidicon camera and FM tape recording channels does appear to be feasible.

C. Kinescope Recording

The material on this subject in the final report was not complete, in that the proposed developmental kinescopes were not then available for evaluation. Several engineering-model versions of this kinescope were obtained subsequently and the tests on these, reported herein, give a reasonably good indication of the obtainable phosphor-image quality. It is believed that the results justify the predictions on overall performance which were made in the final report.

II. SUMMARY

A. Optics, Ground Imaging System:

The components of the Schmidt-type system have been tested and reported. This report covers the measurements on the segmentation hubs and prisms, the alignment of the complete system, the mechanical aspects of the systems, the photographic tests, and recommendations for future systems.

B. *Magnetic Video Recording Systems:*

A number of changes were made in the FM recording system and the present status of this system is presented through block and schematic diagrams.

Considerable work was accomplished in efforts to reduce the flutter, skew and amplitude variations. Head performance on the developmental recorder comparable to the best observed on the loop machine is obtainable using increased tape tension and larger reel motors. It was found that tape skew was very low provided that the distance between the used faces of the edge guides was no more than about one mil more than the width of the tape.

The wiring and cabling of the head circuits were changed to minimize all forms of coupling. Cross-talk is now about 40 db down and all six channels can be used with no interference between channels.

After being designed and constructed the basic delay line from which a series of related bandpass filters could be derived was found to be inadequate. It is still believed that this approach is feasible and is perhaps the only way now known which will provide frequency division multiplexing without reliance on reverse playback. The use of other multiplexing systems and recording methods is discussed.

C. *Kinescope Recording:*

Three kinescopes were tested; two were development tubes and a third was a previously evaluated tube used as a reference. The present kinescope response was not as favorable as that of the referenced tube.

As a result of these tests it is believed that light scattering and image spread in the phosphor are limiting the rendition of fine detail as much as the distribution in the beam spot itself. It now appears that a ten-inch P-16 tube may be required to get a 560 TV-line response of about 75 percent or better as measured on the phosphor. The development of a new thin transparent phosphor by the RCA tube department may eventually permit satisfactory results even in a five-inch tube.

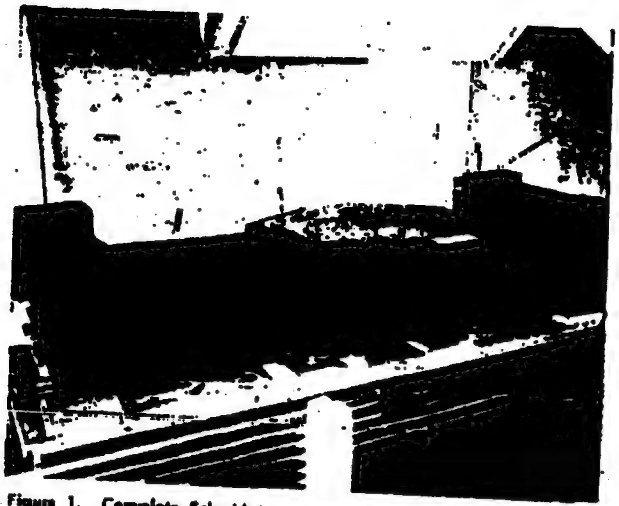


Figure 1. Complete Schmidt-type Camera and Segmentation System

Figure 3. Closeup View of Phasing Dial

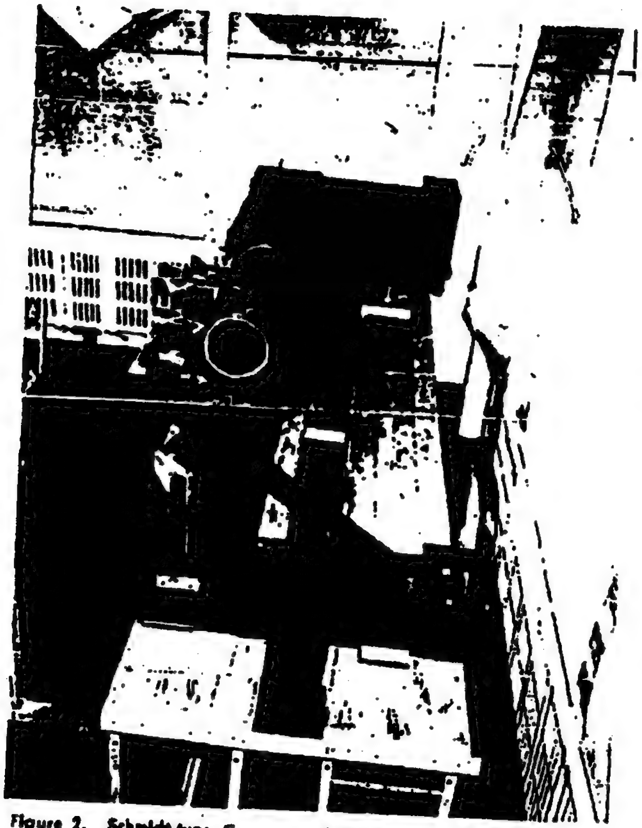


Figure 2. Schmidt-type Camera and Segmentation System with left covers removed

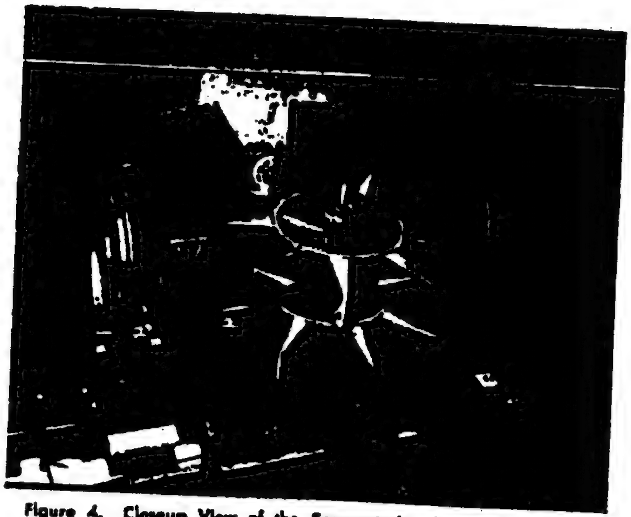


Figure 4. Closeup View of the Segmentation Drums and Prism

b. Prism Mounting Face

In measuring the parallelism error between the drum faces and the shaft axis, means had to be established to identify and fix such a direction. This was done by supporting the ground bearing surfaces on the shaft at either side of the drum in V-blocks. In order to make the supports somewhat self-aligning, the V-blocks were lined with manila paper, light springs lined with manila paper were applied to force the axle down into the V-grooves, and a light lubricating grease was applied. A plane parallel plate was adjustably secured to the end of the shaft and adjusted parallel to the rotation axis by observing that it remains square to the autocollimator after the drum is rotated 180°.

The stability of the axis so determined was tested by securing the V-blocks and the autocollimator in the relative positions described at the end of the preceding paragraph, then rotating the plane parallel on the shaft axis 40°, re-squaring it to the autocollimator for one position of the drum and then checking squareness after the drum is rotated 180°. This was done in 40° steps all the way around the drum. It was concluded from the results of these observations that the axis of rotation did not change direction more than 5 seconds during rotation, and the autocollimator was then squared to its mean direction.

A second autocollimator was pointed to observe the reticle of the first along a line that cleared the drum shaft, after a large flat had been squared to the first autocollimator to permit its transfer to the new observing position. A flat mirror was then clamped to each drum face in turn so that it overhung the edge of the drum. By rotating the drum into positions separated by 180°, the mirror can be brought before either autocollimator and the angle between drum face and shaft axis read with the filar micrometer. The measurements showed three of the faces on the lower drum to be out of parallel with the shaft axis by more than the allowable ±15 seconds. The maximum error was about forty-five seconds. Seven faces of the upper drum exceeded the fifteen second tolerance, the maximum being also about forty-five seconds. The fifteen second tolerance was originally based on a drum rotation of 3° during a five millisecond exposure. With a drum rotation of 0.9° during a 1.5 millisecond exposure, the forty-five second error should not be excessive, although little margin theoretically remains to take care of increases in the exposure interval. In the case of each drum, the faces that were out of parallelism tolerance intersected the shaft axis on the side of the drum away from the drive gear, in the direction of the shaft extension. This would seem to indicate the presence of a systematic error in the vendor's method of test, or at least a systematic difference between the two methods of checking.

Although the parallelism between drum faces and shaft axis is acceptable, experience with its measurement indicates that the drum drawing should not only specify the desired parallelism tolerance but should also reference a specification for performing the tests or, at least, for defining the rotation axis. It should be noted that when the drum rotates on its tapered roller bearings, the direction of the rotation axis is somewhat more unstable than when the bearing journals are supported in V-blocks, as discussed previously in this report.

3. Alignment of the Optical System

a. ALIGNMENT OF SCHMIDT-TYPE CAMERAS

Figure 5 represents a plane view of the framework PQRT of the optical system. This framework consists of two L-shaped parts, which are joined to a central section J along lines XX and ZZ, and to which they are secured by 32 screws. The L-sections are equipped with leveling shelves, S, and are mounted on three jacks. Before securing the L-sections to section J (by tightening the 32 screws) the L-sections are adjusted to proper height and leveled by placing a sensitive level on shelves S. The level sensitivity is about one minute per scale division, and is carefully adjusted beforehand by setting it on an optical flat supported by a leveling table.

The two L-sections mount folded optical systems whose optical axes consist of the parallel segments FA and GB, and the common segment AB. Points A and B are indicated on the upper surfaces of the L-sections by prick punch marks, according to the dimensional requirements of the design, and the line AB is scribed using a straight edge. In order to make it possible to scribe this line with a straight edge whose length is only about one-half AB, plumb lines are carefully supported above points A and B. Two additional plumb lines are supported at C and D, and brought by careful sighting into the plane of those at A and B. The technique is to sight along DA with the eye close to D, and along CB with the eye close to C. The plumb line close to the eye will appear as a blurred vertical bar against which it is easy to judge the centering of the other two plumb lines by moving the head slightly in a horizontal direction during the observation. When the other two plumb lines both appear centered in this bar, the three plumb lines are in a single plane. By observing and making notes of the directions in which C or D might be moved to bring them into a common plane with A, and by noting the same with respect to B, it is possible to deduce the adjustments that must be made in the positions of C and D to bring them both into the plane of A and B. This requires patience and care but is not especially difficult. With the points C and D prick-punched as indicated by the final positions of the plumb bobs at C and D, the line segments AC and DB are scribed.

Segments AF and BG are laid out perpendicular to AB, using the familiar compass and straight edge method of geometry as indicated by the construction about the arbitrary center K.

Spherical mirrors are located at F and G according to the dimensional requirements of the design, and are substantially centered on lines AF and BG respectively. It is necessary that the center of curvature of mirror F shall lie in the plane determined by line AF and the plumb line at A, say at F^1, and that the center of mirror G shall lie at a corresponding point G^1. This is brought about by suspending a plumb line above the point M on AF, after which the eye placed near A can observe when plumb lines A and M, and the image of plumb line A in mirror F are in a common plane. Coplanarity of these lines is attained by lightly tapping the mirror to rotate it on a vertical axis until they are observed to be in alignment. The center of F is then at F^1. The procedure for mirror G is identical.

At each of the points A and B are two plane mirrors m and n respectively. The mirrors of each pair are supposed to lie in a single plane normal to plane FABG and at 45° to line AB, as indicated by the lines m and n that represent their reflecting surfaces. U and V are aspheric Schmidt corrector lenses centered nominally above line AB and located along AB according to the dimensional requirements of the design. Mirrors m are adjusted by removing corrector U and placing an illuminated pinhole at the location of its center. The mirrors m are then adjusted until the light from the pinhole which they reflect to mirror F is returned by them to two images of the pinhole that substantially coincide with each other and with the pinhole. This is possible because mirrors m reflect the center of curvature of spherical mirror F to the center of corrector U. The planes of mirrors m are easily adjusted to substantially contain the point A by making them have linear contact with the plumb line suspended above A. This condition is judged visually and should be maintained at every stage in the adjustment of mirrors m. The same procedure is used to adjust mirrors n. Correctors U and V are then restored to their nominal functioning positions. Because of their very low refracting power, the correctors may be located and squared by ordinary sighting means, using the plumb lines suspended above A, B, C, and D.

b. ALIGNMENT OF 35 MM CAMERA BODIES AT FOCAL PLANE OF OPTICAL SYSTEM

A large aluminized optical flat was placed at the position J, see Figure 5, facing the Schmidt Optical System under alignment. A point source was placed at the approximate position A, where the center of the camera film frame should be. An autocollimator was placed at an intermediate position along AC so that the optical flat could be aligned parallel to the corrector plate, U. The point source was then moved about until the in-focus image of the source fell back upon itself. The system was then autocollimated. A 35 mm illuminated transparent slide was then centered at this point after the removal of the point source. The slide was held at the film plane by the 35 mm camera body at A (the camera body used was the standard Argus, Model A). Rather than repeat the above procedure for the other Schmidt System, the optical flat was removed and the system FAC was used as a collimator for system DBG. The illuminated slide at A was imaged on the ground glass held by the camera body at B. The camera body was adjusted for best focus and proper centering of the image.

C. DRUM AND SHUTTER PHASING

The operating cycle of the segmenting optical system comprises a sequence of 36 exposure phases. These phases are spaced at equal intervals of drum and shutter rotation and therefore at equal intervals of time when the parts are driven at uniform rotational speeds. The drums normally rotate at 100 RPM, but for the purposes of photographic testing, a special speed reducer is used to reduce this rate to 7½ RPM.

AT 100 RPM, the normal television exposure time is 0.0015 second, during which the mirrorstat drums rotate $\frac{100}{60} \times 360^\circ = .0015 = 0.9^\circ$. With a photographic shutter operating at $\frac{1}{50}$ second, the drum speed must be X RPM where: $\frac{X}{60} \cdot 360^\circ \cdot \frac{1}{50} = 0.9^\circ$.

This makes X = 7½ RPM. At this speed, the drums again rotate 0.9° during the exposure time of $\frac{1}{50}$ second, which is used in photographic testing.

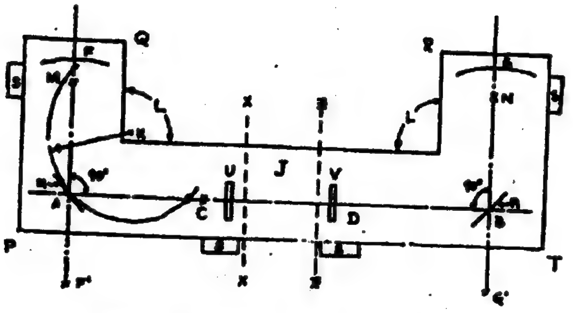


Figure 5. Framework for the Optical System

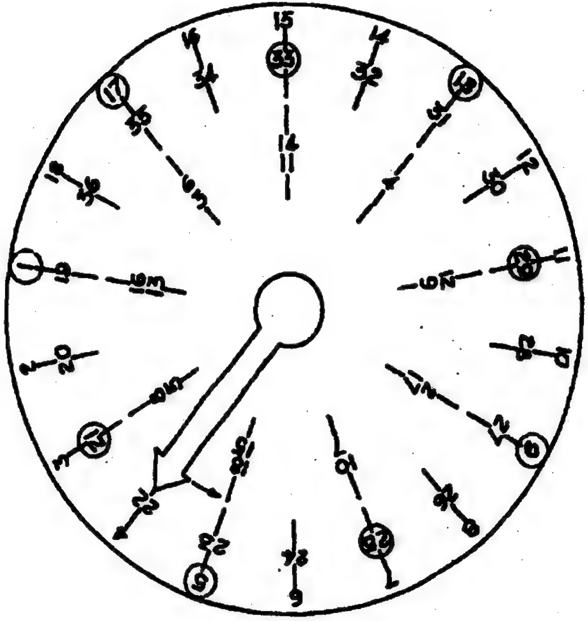
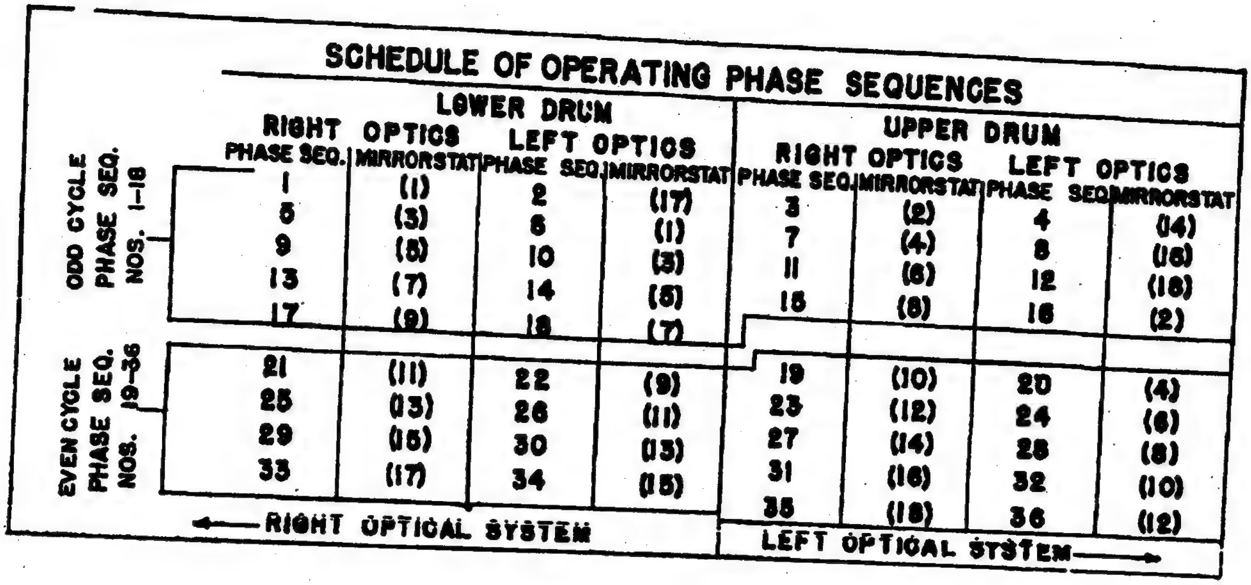


Figure 6. Figure Dial (circled numbers are colored red)



SCHEDULE OF OPERATING PHASE SEQUENCES

	LOWER DRUM				UPPER DRUM			
	RIGHT OPTICS		LEFT OPTICS		RIGHT OPTICS		LEFT OPTICS	
	PHASE SEQ.	MIRRORSTAT	PHASE SEQ.	MIRRORSTAT	PHASE SEQ.	MIRRORSTAT	PHASE SEQ.	MIRRORSTAT
ODD CYCLE PHASE SEQ. NOS. 1–18	1	(1)	2	(17)	3	(2)	4	(14)
	5	(3)	6	(1)	7	(4)	8	(16)
	9	(5)	10	(3)	11	(6)	12	(18)
	13	(7)	14	(5)	15	(8)	16	(2)
	17	(9)	18	(7)				
EVEN CYCLE PHASE SEQ. NOS. 19–36	21	(11)	22	(9)	19	(10)	20	(4)
	25	(13)	26	(11)	23	(12)	24	(6)
	29	(15)	30	(13)	27	(14)	28	(8)
	33	(17)	34	(15)	31	(16)	32	(10)
					35	(18)	36	(12)

←RIGHT OPTICAL SYSTEM | LEFT OPTICAL SYSTEM→

Figure 7. Schedule of Operating Phase Sequences

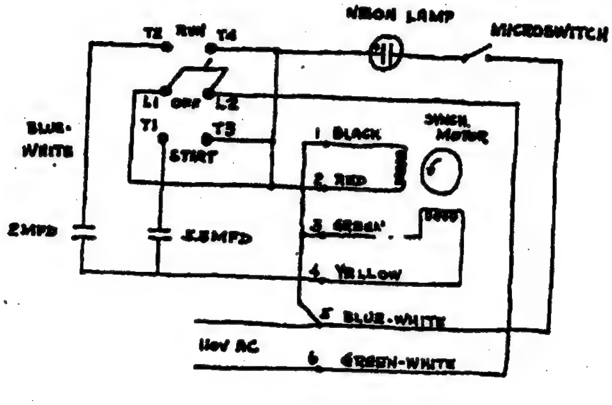


Figure 8. Electrical Wiring Diagram of the Synchronous Motor, Starting Capacitors, Phasing Lamp and Switches

The drums are driven at 100 RPM by a 3600 RPM motor using a model 10B24R speed reducer made by Metron Instrument Co., Denver, Colo. Their model 10B320S reducer is used to obtain the 7½ RPM speed. Interchange of the speed reducers requires reversal of the motor direction to keep the upper drum rotating counterclockwise as seen from above. The two speed reducers are dimensionally interchangeable in all other respects. Details of the method of reversing motor rotation are given elsewhere in this report.

During the exposure cycle each drum rotates two full turns, the upper drum counterclockwise as seen from above, and the lower drum clockwise. The first of these turns is called the odd cycle and the second the even cycle, as will be more fully defined later in this report. Each rotating shutter correspondingly rotates three full turns. The shutters function as optical "switches" to regulate the delivery of light from the drums to the right and left branches of the optical system. "Right" and "left" are referred to an observer who views the system along the direction of the light as it enters the drum compartment. Thus, the shutters admit light alternately to the two branches from the lower drum, then alternately to them from the upper drum, and so on. The drums and shutters are all connected together through a gear train, which is driven by a 3600 RPM synchronous motor. It is important in the completely assembled equipment that it be possible to determine by a simple routine examination that these moving parts have a proper relation to each other, and to restore them to correct relation if they have moved. To this end, indicating means are provided to make such checks easy.

A number has been punched on each corner of the upper surface of each drum. These are the mirrorstat numbers which identify each cooperating pair of reflecting surfaces. They do not appear in numerical order around the drums, but all the numbers on the lower drum are odd, and on the upper even. The numbering of the mirrorstats exactly corresponds to the numbering system that appears in previous report (Progress Report #7, p. 10, F. 8, etc.).

A dial is located on the top of the drum compartment cover, shown in Figure 6, and is provided with a moving hand or pointer that rotates counterclockwise with the upper drum. The dial is numbered serially in the counterclockwise direction at 20° intervals. An outer circle of numbers ranges from 1 to 18 inclusive, while a smaller circle correspondingly ranges from 19 to 36 inclusive. Each of the eighteen positions about the dial is, therefore, identified by two numbers, which are called the phase sequence numbers. They correspond to the 36 exposure phases which occur during every two rotations of the drums. These numbers are white with the exception that number 1 and every fourth number thereafter is colored red. As a result, alternate numbered positions are marked with two white numbers, while the remaining positions each have one red number.

Corresponding to the dial positions that have red numbers, additional numbers appear in pairs closer to the center of the dial. These pairs make up an outer circle of even numbers that correspond to the mirrorstat numbers on the upper drum, and an inner circle of odd numbers that correspond to the mirrorstat numbers on the lower drum. Compared with the mirrorstat numbers on the upper drum, the even numbers of the outer circle have the same order *in the opposite sense about the center.* The odd numbers of the inner circle appear in both the same order and same sense about the center as the mirrorstat numbers on the lower drum.

Near the edge of the dial an observation port appears in the drum compartment cover. A pointer is fixed beneath this port, at an angle 10° clockwise from the axis of bi-lateral symmetry for the entire system. The drums must be phased so that their numbered corners line up directly under this pointer as they pass the observation port, beginning with corner 16 of the top drum in line with corner 13 of the bottom drum.

When these two corners are lined up with the stationary pointer, the moving pointer should be set to indicate position 1-19 at the edge of the dial. One of the openings in the rotating shutter before the right optical system should then also be in its lowermost position. When the mechanism is then turned to swing the moving pointer 20° counterclockwise to position 2-20, one of the openings in the rotating shutter before the left optical system should be in its lowermost position. The drums and shutters are then in their proper relative positions. A hole in the rotating shutter is lowermost when a notch in the edges of the shutters is in a horizontal plane as seen through the shutter shaft axis as seen through one of the two access doors at the rear of the drum compartment cover.

The first rotation, which starts with the pointer at position 1-19 and the opening in the right shutter lowermost, is called the odd cycle of operation. The second rotation is called the even cycle, after which the odd cycle starts over again, and so on. The odd and even cycles are identified by the flashes of a lamp at the rear of the assembly. This lamp is energized by a cam and microswitch each time an opening in the right rotating shutter reaches the lowermost position. The odd cycle is identified by the flashes occurring when the moving pointer is directed toward red numbers in the outer circle of phase sequence numbers (1 to 18 inclusive). During the even cycle, the flashes occur when the pointer indicates red numbers in the inner circle. The even cycle phase sequence numbers are 19 to 36 inclusive.

When the phase sequence number has been identified by observing the dial pointer positions in relation to the occurrence of the lamp flashes, the particular mirrorstat, drum, and optical system which are functioning to produce an image are identified by consulting the schedule of operating phase sequences, Figure 7. This is also attached to the back of the drum compartment cover.

For example: If the rotating pointer is directed to position 12-30 and the lamp flashed when it passed position 11-29, the phase sequence number is 30 (in the even cycle). The schedule then shows that for phase sequence number 30, mirrorstat 13 on the lower drum is directing light into the left optics. If the pointer is directed to position 7-25 and the light is not turned on, the system is at phase sequence number 7 (in the odd cycle). The schedule indicates mirrorstat 4 on the upper drum to be directing light into the right optics. In this last case, however, should the light be turned on with the pointer in position 7-25, the phase sequence number would be 25 (in the even cycle), and mirrorstat 13 on the lower drum would be directing light into the right optics.

The phasing of the drums may be checked very readily by turning the dial pointer to any one of the red numbered positions and observing the alignment of the drum corners through the observation port. For example, if the pointer is at position 13-31, corner 4 of the upper drum should be in line with corner 1 of the lower drum and with the stationary pointer, as indicated by the numbers 4 and 1 beneath the moving pointer. Drum phasing may be similarly checked when the pointer is at any other red numbered position. It is not necessary to know the phase sequence number in order to check drum phasing.

In order to check the phasing of the rotating shutters, the drums and the dial pointer must first be properly phased. A check for this is given in the preceding paragraph. The right shutter should then have an opening in lowermost position when the dial pointer indicates one or the other of any two adjacent (40° apart) red numbered dial positions. The left shutter should then have an opening in lowermost position when the pointer turns just 20° counterclockwise to the next phase sequence number on the dial. As in the case of the check for drum phasing, the check for shutter phasing does not require the phase sequence number to be known. The observation doors at the back of the drum compartment give access to the rotating shutters. In order to make it possible to judge if a shutter opening is at its lowermost point when the shutter is viewed edge-on through the door, three indexing notches are cut in the edge of each shutter. When a shutter opening is lowermost, an indexing notch appears at the same height as the axis of the shutter drive shaft. Corresponding notches in the adjacent fixed baffle plates are at the same height as the drive shaft axis and make it easy to judge shutter phasing.

d. Alignment of Prisms on Drum

The objective in aligning the prisms on the drums was to set all the left-hand prism faces on each drum parallel with the rotation axis of the drum within an angle of five seconds (in accordance with Progress Report #7, p. 12). Optical tests which were made to determine the stability of the direction of the drum shaft during rotation showed the direction to wander through an angle of about thirty seconds. The autocollimator was, therefore, set square to the mean direction of the axis, and the left-hand prism faces were set parallel with this direction within thirty seconds. Although the five second accuracy goal on prism alignment may be readily met using standard optical alignment means, experience with the model has shown that further development of the bearings to make the rotation axis stable within comparable limits is necessary before five second tolerances or prism alignment are practically justified.

(Note: When the system was fully assembled for testing, it was noted that the images were somewhat unsteady, particularly in a direction parallel to the drum shaft axis. This was partly due to vibration of the entire equipment in resonance with the table on which it was mounted. The frequency of this resonance was satisfactorily reduced by setting the six mounting jacks on sponge rubber pads about 12" x 12" x 1½". It was then noticed that the images projected by certain of the mirrorstats appeared consistently steady while those projected by others consistently showed motion parallel to the drum axis. The addition of opposing screws to the retaining caps for the top bearing of the upper drum and the bottom bearing of the lower drum permitted the very careful readjustment and reseating of the drum shaft roller bearings. Also, the very careful setting of the locations and clearances of the spiral bevel driving gears reduced the parallel motion to the point where it was not distinguishable from random vibration effects. No measurements were made after that time to determine if any improvement had been made in the approximately thirty seconds instability in the direction of the drum rotation axis.)

During the adjustment of the prisms on the drum, the prism clamps were partially tightened and the prisms adjusted to substantial parallelism with the rotation axis by repeatedly tapping the metal prism base. Adjustment was judged with an autocollimator squared to the rotation axis by adjusting it and a plane parallel mounted on the end of the shaft until the parallel appears square to the autocollimator for drum positions that are 180° apart. By then squaring a large optical flat to the autocollimator, the instrument could be transferred to a suitable position for observing the prisms and again squared to the drum axis. In its final observing position, the autocollimator received a return from both the large reference flat and the prism under adjustment, which made it possible to make a direct comparison.

e. BALANCING OF PRISM DRUMS

Because the size of the prisms distributed around the drums varied, the center of gravity shifted away from the rotational axis of the drums. Using an unfinished drum as a mold, Woods metal was poured into the proper segments. The molded piece of metal was then attached to the wheel to be balanced. The molded piece of Woods metal was purposely made too large so that the center of gravity could be brought up to the axis of rotation gradually. The latter process was quite simple because of the low melting point of Woods metal (about 80°C). Because the center of gravity of molded Woods metal could not be placed exactly on a line through the axis of rotation and the unbalanced center of gravity, additional washers made of Woods metal had to be placed on various parts of the drum. The drum was considered statically balanced after repeated movements of the drum resulted in no backward motion of the drum after it came to rest.

4. Auxiliary Mechanics of the Optical System

a. COVERS AND BAFFLES

In addition to the supporting framework of the optical system, the system is provided with baffles and light tight covers to control, exclude and absorb unwanted light. Each branch of the optical system is covered with a light tight sheet aluminum cover which encloses all but the corrector lens. The covers are L-shaped, extend to within about 3 inches of the corrector plates, and are fitted with six baffle partitions each to exclude and trap undesired light as far as possible. The baffles are finished with black flack on both surfaces, and the other interior surfaces of the covers and the base on which the rest are finished dull optical black. At the end of each cover nearest the corrector plate, the first baffle is fitted with two flanges to mount Ilex No. 5 shutters for the photographic testing. These baffles are followed in each cover by two other baffles at about fourteen inch intervals. These additional baffles each have two circular openings to admit light from the upper and lower drums. Each opening is large enough to clear the useful light beam by ½ inch on the radius. Between the diagonal and spherical mirrors are three baffles in each cover, beginning about two inches from the spherical mirror and spaced at about twelve inch intervals. These baffles have long vertical openings with rounded ends since they must permit passage of light from the diagonals to the spherical mirrors and back again to the space between the diagonals near where the image appears. The ½ inch clearance for the useful light is maintained here also, as far as practical.

b. CAMERAS AND FILM TRANSPORT

Adjustable mounting brackets are provided to mount two photographic camera frames for photographic testing. These are located close to the diagonal mirrors and the cameras are available through access doors at the rear of the corner section of each L-shaped cover. The camera frames act merely as film supports, their lenses, shutters and irises being removed. Controls extend from the camera frames through the cover to permit advancing and rewinding the film without opening the access doors. The control knobs on top of the covers advance the film and those on the sides rewind it. The cable releases that extend through the covers above the cameras are depressed to permit film to be advanced to the next frame and are released as soon as film advance begins, to stop the advance at the proper point. The front of each camera is painted dull optical black to absorb non-useful portions of the image that lie beyond the camera matte.

When the L-shaped covers are bolted in place and all seams, door hinges and edges, and corners sealed with Scotch Photographic Tape, the compartments that enclose the mirrors and camera frames are light tight and light may be admitted to them only by tripping the shutters. Two shutters are provided, and may be moved from one optical system to the other by unscrewing them from their flanges. Access doors are provided for this purpose at the sides of the back panel of the cover for the center section. Near the upper and lower corners of each door is a hole to accommodate one of the shutter cable releases.

c. SEGMENTATION COMPARTMENT

The housing for the center section of the optical system houses the motor driven segmentation drums. It comprises four enclosure panels and four baffle assemblies. The enclosure panels are a heavy metal floor, front, back and cover. Two inside baffles are screwed to the floor, and two outside baffles screwed to the front panel form with them continuous access tunnels through which light from the object space reaches the mirrorstats on the rotating drums. The center compartment can obviously not be made light tight, but all its inner surfaces are coated with black flack to dissipate unused light that cannot be prevented from entering the drum compartment through the tunnels that lead through the front panel.

The drum compartment is supplied with power through a cord that passes up through the compartment floor near the front. The motor is controlled by a two stage switch on the back panel that first connects a starting capacitor in the circuit, and then a running capacitor. Two thrusts are necessary to fully actuate the switch in either direction, and in starting a five second to ten second lapse between thrusts is recommended to give time for oscillations to damp out before switching in the running capacitor.

The red phasing lamp is mounted beside the motor switch. This is a neon lamp with a built-in resistor in the lamp socket for 110 volt operation that flashes each time the right shutter has an opening in the lower most position. Its operation may be better observed under certain conditions if the red bullseye is removed. Figure 8 gives the electrical wiring diagram of the synchronous motor, starting capacitors, phasing lamp and switches. The motor connections shown are for operation with the 320X speed reducer or 7½RPM of the drums. For operation with the 24X speed reducer or 100 RPM of the drums, reverse either the red and black or green and yellow motor leads.

The cover panel of the center compartment is provided with a shaft hole and a covered observation port. The upper drum shaft extends through the shaft hole, and the phase indicator dial is affixed to the cover concentric with the shaft. A chrome plated pointer is affixed to rotate with the shaft and sweep the dial. To the rear of the dial and at one side, the schedule of operating phase sequences is affixed to the cover under a protective plastic sheet.

d. OPERATING SEQUENCE

Once all the mechanical parts are properly phased as described elsewhere in this report, the best procedure for photographic testing is:

1. Decide which branch, left or right is to be tested, locate shutters and load cameras accordingly.
2. Decide which drum, upper or lower, is to be tested and locate on the schedule of operating phase sequences the column of phase sequence numbers that corresponds to the branch and drum selected.
3. Start the motor and switch to running capacitor.
4. With one person watching the moving dial pointer, have a second person call out the lamp flashes until the flashes occur when the pointer is indicating red numbers on the inner circle of the dial, showing the system in the even cycle of operation.
5. The dial watcher then watches the first phase sequence number on the outer circle at which exposure is to be made, and releases the proper shutter when the pointer reaches this position in the *odd* cycle of operation.
6. The second person then advances the film and the process is repeated to produce an exposure at the second phase sequence number of applicable column of the schedule, and so on.
7. When phase sequence numbers in the even cycle are reached, continue to proceed as in 4, 5, and 6 above, except change "inner" to "outer" and vice-versa, and change "even" to "odd" and vice-versa.

5. Photographic Tests with Completed Camera

a. TEST AREA

The completed segmentation camera was set up on the 8th floor of a building where a view down the Delaware River was available through two 52-inch wide windows. The right-hand side of the camera covered the Camden side of the field of view of the camera through one window, and the left-hand side covered the Philadelphia side through the other window. It was possible to straddle the dividing frame between windows and avoid any restriction of the field of view or of the aperture of the system by the window frames.

The supporting frame work was first set up on its six jacks, levelled and bolted together. The jacks sat on a 12 foot x 4 foot laboratory table. Mirror alignment was then checked by the plumb line technique described elsewhere in this report. The rotating drum assembly was set in position and bolted, and the covers assembled and bolted in place. All seams were taped with black photographic Scotch Tape to exclude light.

After some work on the bearing seats and drive gear adjustment to reduce image jump, and after 12″ x 12″ x 1½″ sponge rubber pads were placed under the six jacks that support the camera, it was considered to be in readiness for the tests. The drums and shutters were phased according to the scheme of adjustment discussed elsewhere in this report, and the dial pointer was set in proper relation to the drums.

b. Test Procedure

The small Argus camera bodies were located to support photograph film in the focal plane of each side of the segmentation camera. These cameras had their lenses and shutters removed, while large photographic shutters were mounted in baffles close to each corrector lens to control entrance of light into each side of the optical system from the upper and lower drums. This arrangement required each side of the segmentation camera to be completely light tight, but avoids the limitations that would arise were shutters used at or near the focal planes. By placing the shutters as close as possible to the corrector lens, shutter diameter was minimized. The tests were made by appropriately tripping a shutter, advancing the film by hand, again tripping the shutter, etc., just as when an ordinary still camera is used. A double series of photographs was made, one with the drums rotating continuously under power at 7½ RPM and one with the drums stationary at the time the shutter was tripped.

c. Discussion of Results

The tests had two main objectives:

1. To show that the device is capable of photographing a continuous strip in a series of 36 partially overlapping segments which cover the field for which the system has been designed.
2. To show that the quality of the images of distant objects is not reduced by the motion of the segmentation drums.

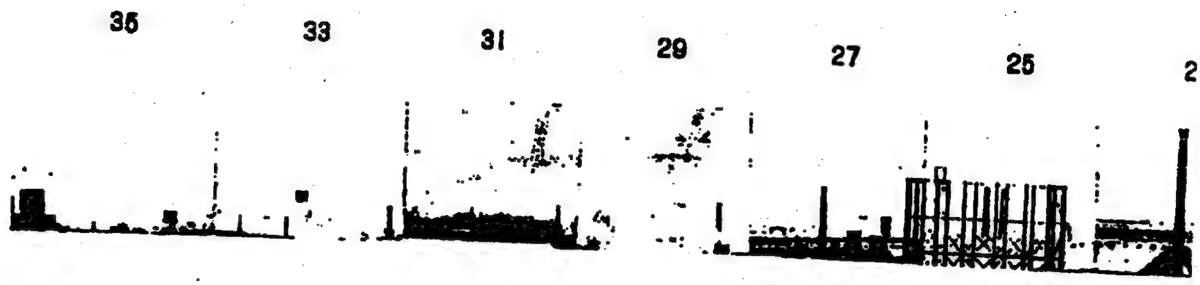
The first objective was met, as far as field coverage is concerned, by photographing the same field with a wide angle view camera and computing the angle from the size of the image and the focal length of the view camera lens. If the focal length of the view camera is f, and the distance on the view camera negative between the extreme points of the segmentation camera field is w, the segmentation camera field angle is $2 \cot^{-1}(2f/w)$. Measured in this way, the field angle of the segmentation camera is compared with a design value of 64.172°. Figure 9 shows a set of contact prints made from the 36 negatives. The set is trimmed and mounted in a continuous strip to show the continuity of the scene. The strip has been presented in two sections to conserve the length of the reproduction.

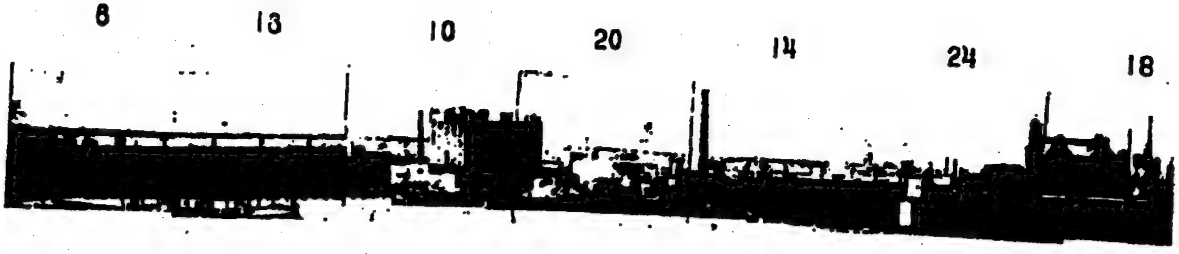
The second objective is accomplished by comparing pictures made when the segmentation drums are in motion, with corresponding pictures made when the drums are at rest. This is a more difficult objective to accomplish because the pictures to be compared cannot be taken simultaneously. Differences in atmospheric conditions and illumination conditions, therefore, occur between pictures that are to be compared. These were minimized by photographing one set of sequence numbers statically and then immediately afterward photographing them dynamically, the entire operation occupying not more than ten to fifteen minutes. During the tests, thermal effects in the atmosphere were sometimes distinctly noticeable on the ground glass focusing screens in the cameras, and illumination conditions changed due to drifting clouds and changing time of day. For quality comparison between static and dynamic conditions, four sets of negatives have been selected that appear most alike as far as thermal disturbance effects and illumination conditions are concerned. These are shown in Figure 10 A, B, and 11 A, B.

All exposures were made at a shutter speed of 1/50 second which was a suitable speed for the conditions of illumination, optical speed, and film used. This exposure time corresponded at the 7½ RPM drum speed to the design pulsing time of 0.0015 second at 100 RPM as explained elsewhere in this report. Exposures were made on Eastman Panatomic-X film and tank developed in Microdol developer for six minutes at 68° F.

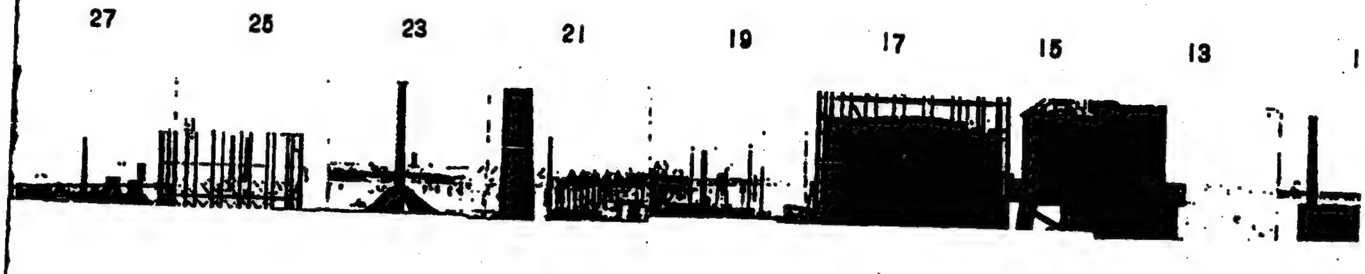
d. Analysis of Mosaic

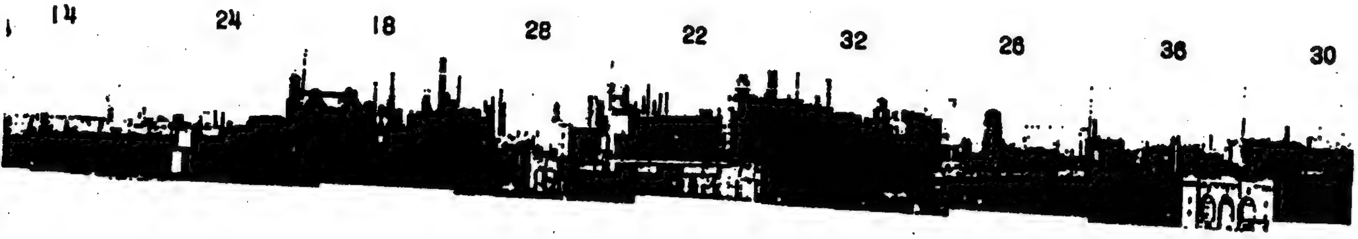
A mosaic has been prepared from contact prints of the 35 mm negatives taken during the dynamic or moving drum tests. The phase sequence numbers of the prints are indicated below each segment as shown in Figure 9. A photograph of the same scene was taken with a 4″ x 5″ camera having a 105 millimeter, or 4.13 inch, focal length lens. This is shown in Figure 12. It was necessary to tilt the camera 45° in the plane of the image in order to obtain the same coverage on the 4″ x 5″ negative as that given by the segmentation system. The linear distance on the negative corresponding to the coverage of the seg-





1





2

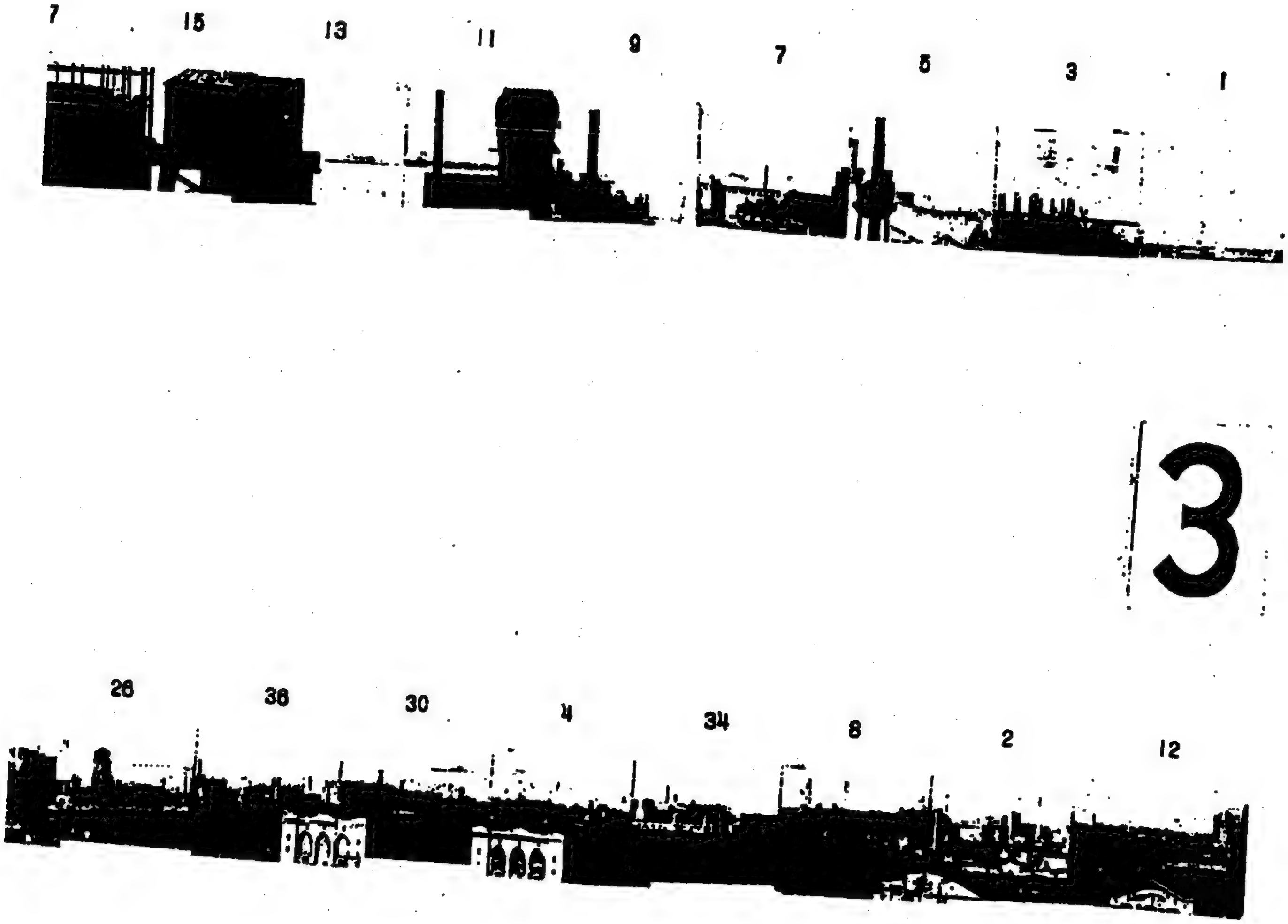


Figure 9. Mosaic made from 36 Negatives Obtained through the Segmentation Camera

mentation system scales 5.45″. The half angular coverage is determined by:

$$\theta, \tfrac{1}{2} \text{ angular coverage}, = \tan^{-1} \frac{l}{2f^{1}}$$

where l = the linear distance on negative, and
f = focal length of the lens.

$$\text{Therefore: } \theta = \tan^{-1} \frac{5.45''}{2 \times 4.13''} = 33.4^\circ$$

The photographs taken with the Argus camera body in the segmentation system have the standard double frame 35 mm format, or a picture size of 0.945″ x 1.42″. When used with the image orthicon, the usable area is 0.96″ x 1.28″. The measured half angular coverage of 33.4° can be compared with the design value of 32.086° which is given in Progress Report No. 5, Table I, p. 13. The additional coverage from the center of the last frame to its edge,

$$\theta = \tan^{-1} \frac{1.42''}{2 \times 38''} = 1.07^\circ, \text{ must be added to } 32.086^\circ.$$

This gives a ½ angular coverage of 33.156° for the segmentation system with the 35 mm camera format. The measured value of 33.4° agrees with the design value within 0.74%. The discrepancy is probably due to use of the nominal value of focal length for the calculation involving the 105 mm lens. A tolerance in focal lengths of commercial lenses may be ±1 to 5%. The half angular coverage of the segmentation system with the image orthicon will be $32.086^\circ + 0.965^\circ = 33.051^\circ$.

Referring again to the Mosaic in Figure 9 the odd phase sequences, 1-35, were taken with the right optical system and covers the left half of the object field as viewed from the camera position. The even numbered frames were taken by the left optical system and covers the right half of the object field. The distances to some of the prominent objects in the frames are given below:

Frame Sequence Number	*Object*	*Distance in Nautical Miles*
13, 15	Walt Whitman Bridge	2.56
25	Tank-New York Shipbuilding Corp. ..	2.13
30, 36	Municipal Stadium	3.52
26	Navy crane	4.38
22	Pier 53, Philadelphia Port	1.06
12	Pier 30, Philadelphia Port	0.75
4	Pier 38, Philadelphia Port	0.85
8	Lift Bridge	4.34
12	George Washington School	1.40

Examination of the contact print made for frame 12, shows the width of a window pane image in the George Washington School to be 0.0075″. For the 38″ focal length optics, this represents a subtended angle of:

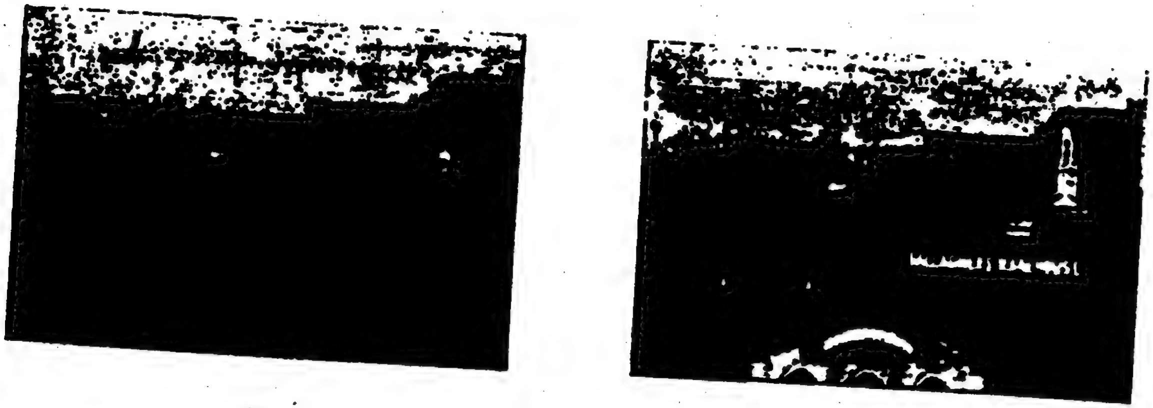
$$\tan^{-1} \frac{0.0075''}{38''} = 42 \text{ seconds.}$$

In order to determine if the rotation of the segmentation drum during exposure time is harmful to picture quality, enlargements have been made of phase sequence frames 12 and 19 for the static and dynamic photographs. Figure 10 A is the static frame and Figure 10 B is the dynamic frame for sequence 12. Figure 11 A and Figure 11 B are the static and dynamic frames, respectively, for sequence 19. Close examination of these enlargements shows that there is no deterioration in quality which may be attributed to the rotation of the segmentation drums during exposure. During the course of the tests, it was found that thermal air currents were the predominate causes of degraded pictures.

6. Recommendations for the Improvement of the Present Model or the Design of a New Model

The Schmidt optics have proven satisfactory. No changes are recommended for these components, although improvements are needed in the mechanical mounts for the spherical mirrors and the diagonal mirrors. Gimbal mounts for the spherical mirrors would make alignment simpler. If a minimum weight system is desired, considerable thought must be given to the possibility of using corrector plate and spherical mirror segments of minimum size. It is probable that the difficulty of alignment of these segments will out weigh any advantages gained by the use of the minimum size components. A study should also be made of other possible folding arrangements of the optical paths so that minimum space is required. A study of the mutual alignment between the segmentation assembly and each optical system should be made so as to devise adjusting procedures and suitable mechanical means for attaining and maintaining such alignment.

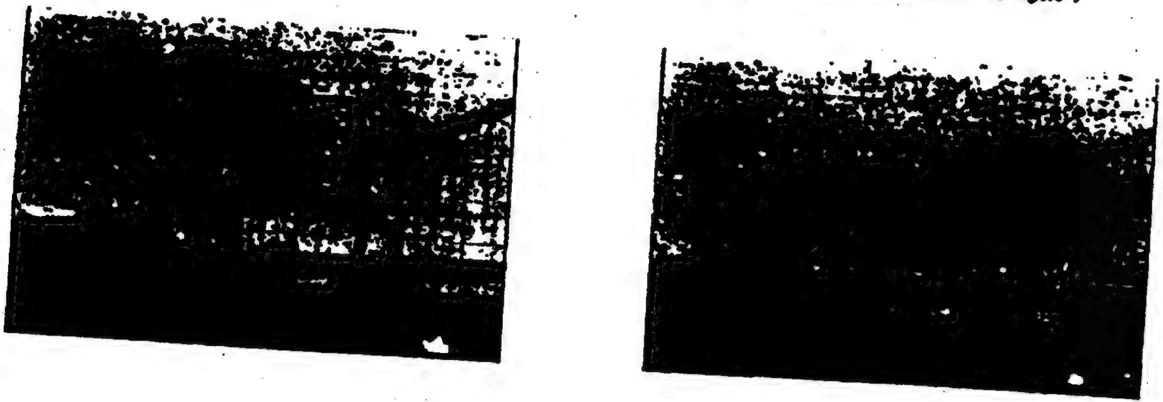
The optical specifications on the reflecting prisms were met by the vendor after agreement was reached on a method of correction of the pyramidal error which was present in the first group of prisms received. The method of sealing the glass prisms to their metal bases has proven satisfactory after the correct formulation and curing cycle for the cement were determined. Further studies should be made to obtain the maximum strength and reliability of the glass to metal bond. The measurement of the pyramidal error and the base angles of the prisms was



(A)

(B)

Figure 10. Comparison of Image Detail between Static, A, and Dynamic, B, Conditions from Sequence 19, Figure 9

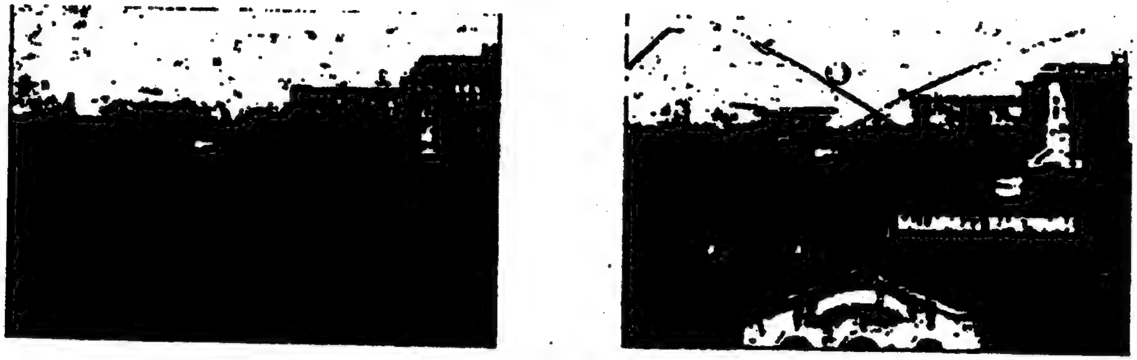


(A)

(B)

Figure 11. Comparison of Image Detail between Static, A, and Dynamic, B, Conditions from Sequence 12, Figure 9

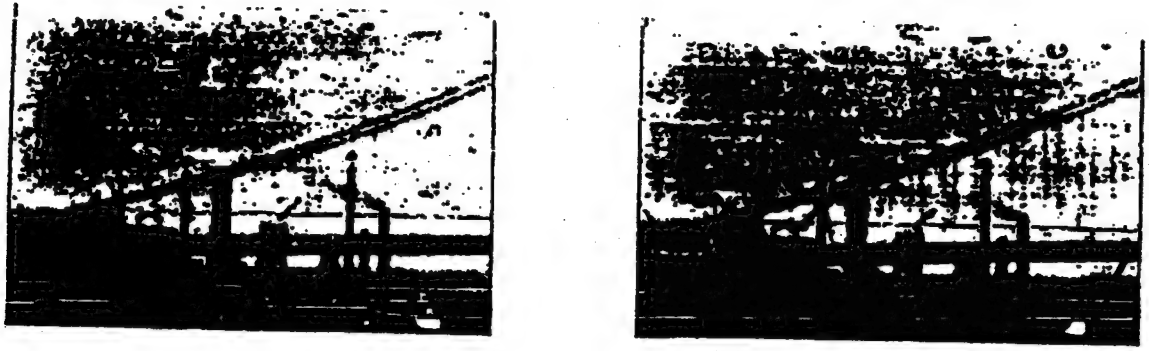
Figure 12. Photograph of Segmentation Scene Taken with a 4 x 5 Camera



(A)

(B)

Figure 10. Comparison of Image Detail between Static, A, and Dynamic, B, Conditions from Sequence 19, Figure 9



(A)

(B)

Figure 11. Comparison of Image Detail between Static, A, and Dynamic, B, Conditions from Sequence 12, Figure 9

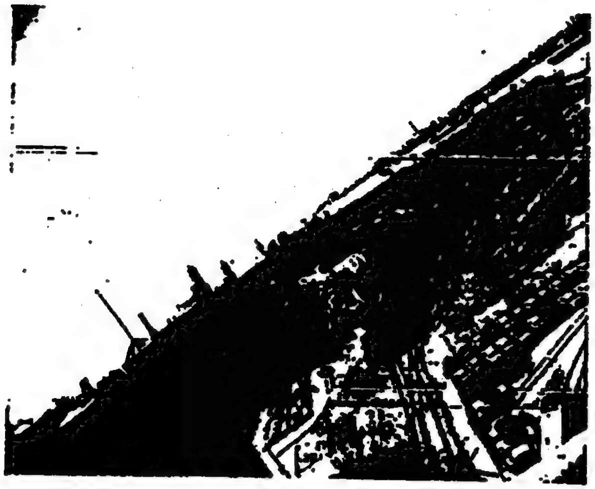


Figure 12. Photograph of Segmentation Scene Taken with a 4 x 5 Camera

made somewhat difficult because of the very weak reflection returned to the autocollimator by the metal base plate. A good polish should be specified for the metal plate. A chrome flash or other hard metallic coating will provide a good reflecting surface. It was found that the color of the aluminum coating on the prisms varied from prism to prism. The absolute reflectivity and the spectral reflectance of the coatings should be specified to prevent variations in the quantity and quality of the light reaching the pickup tube.

The drawings for the drums and prisms should require that identifying numbers are placed on each prism and on the mounting faces of the segmentation drum. It is recommended that the segmentation drum be constructed so that the prism mounting surfaces are of stainless steel. The surfaces should be treated the same as the metal prism bases so that a good reflection is obtained when used with the autocollimator. In the construction of the mosaic from the photographs made with the optical system, it was found that there was a slight alternate vertical displacement of adjacent picture frames. These frames were taken alternately by the upper and lower segmentation drums. This indicated that the axes of rotation of the two drums were not parallel. In view of the fact that the high quality tapered roller bearing gave some instability in the direction of the drum axis, a different design, such as sleeve bearings bored in line for the upper and lower drums, should eliminate both the instability and the lack of parallelism. In general, it was found that neither the commercial grade bearings nor gears were good enough to make possible the desired accuracy of prism adjustment and retain drum orientation stability.

Provisions should be made for a suitable adjusting and securing means for the alignment of the prisms on the segmentation drums. It should also be made certain that the locating pins and the pinholes in the drums are square to the drum faces and the metal prism base bearing surfaces. The high reduction speed reducer contributed to the vibration problem. A specially designed multi-poled motor operating at 150 RPM should reduce the vibration problem. With the present motor drive system, there are torque peaks in the starting and stopping of the mechanism. It should also be mentioned that all gearing should be enclosed as a protection from dirt. A comprehensive structural analysis should be made of a new design to insure rigidity with light weight. The new design should make the alignment of the segmentation drum assembly with respect to the optical systems independent of the jacks that support and level the complete unit.

B. MAGNETIC RECORDING

1. Introduction

The primary objective of the magnetic recording studies was to evaluate the feasibility of multiplexing a wide-band video signal into several narrow-band signals, recording these signals on several channels of a multichannel tape recorder, playing them back at a later time, and, from these recordings, reconstructing the original wideband video signal. Both frequency-division and time-division multiplex systems have been studied. Much time and effort have also been spent on developing the techniques of magnetic recording that allow the multiplexed signals to be recorded on and played back from the tape.

The principal areas of effort covered by this report are:

1. Improvement of the frequency-modulation modulators and demodulators.
2. Modification of the tape transport mechanism to minimize tape flutter, skew, and amplitude variations.
3. Reduction of crosstalk between tape channels.
4. Selection of tape for best performance.
5. Development of frequency-division filters with minimum phase distortion.
6. Evaluation of an existing time-division multiplex equipment in this application.

2. Frequency Modulation Recording Channels

During the period covered by this supplementary report, many changes and improvements were made in the frequency-modulation recording channels. Figure 13 is a block diagram of the recording system which resulted from the investigation.

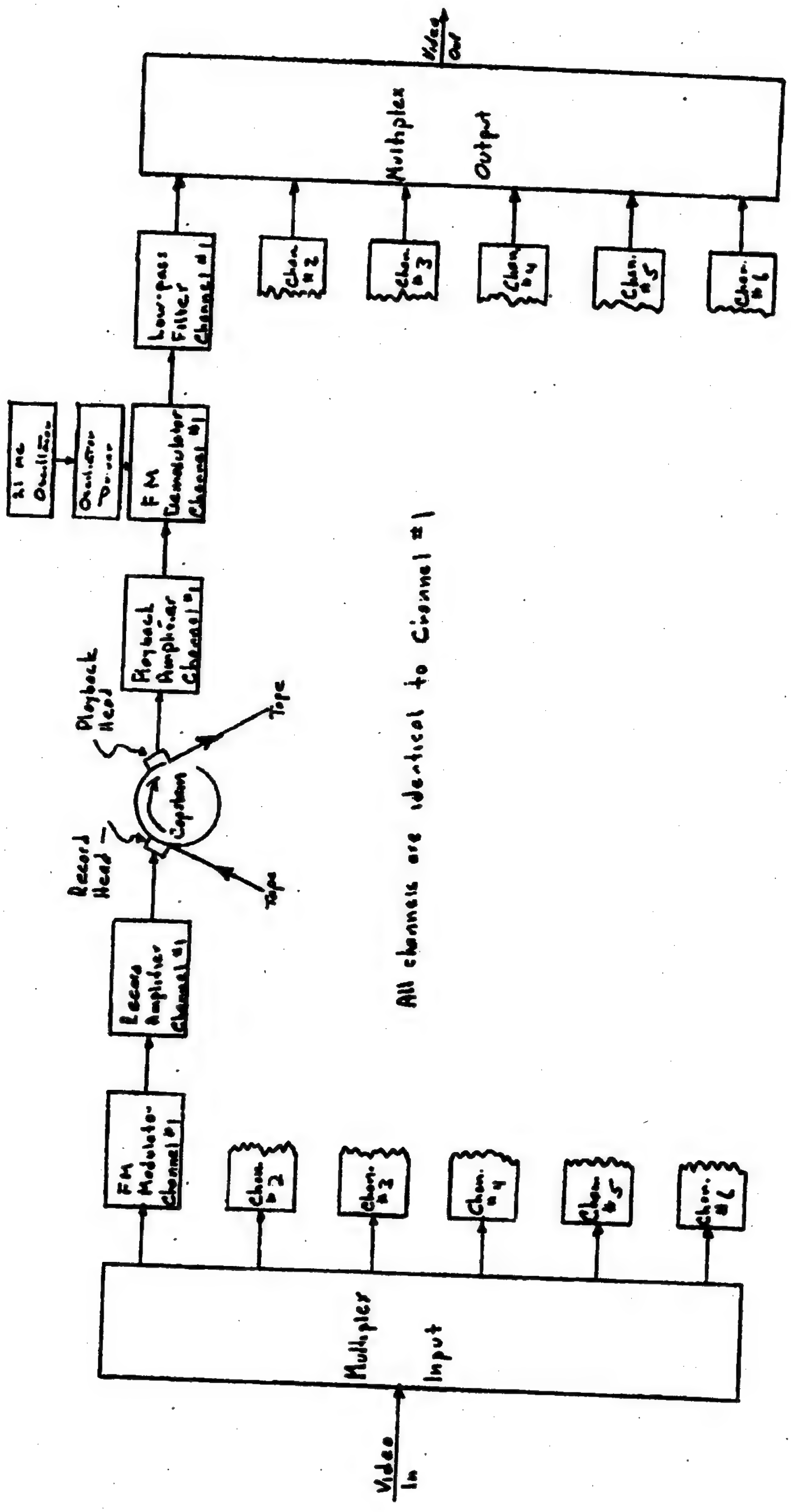
The input and output of the recording system are the multiplexing units which will be discussed later in the report. For this section it is sufficient to note that the input multiplex unit converts the wide-band video input signal into several narrow-band signals and that the output multiplex unit converts several narrow-band signals into one wide-band video output signal.

As is indicated in Figure 13, the input multiplex unit feeds six identical channels in the tape recorder. Five of these channels are used for the multiplexed video while the sixth channel is used for synchronization to insure that playback and recording are accomplished at the same speed so that a true reproduction of the input may be obtained on playback.

The narrow bandwidth recording channels were designed to accept video information with a passband of from three cycles per second to one megacycle per second. The signals from the input multiplexer are routed to their respective FM modulators. Each modulator, Figure 14, consists of a 6CL6 video amplifier feeding a 6CL6 reactance tube modulator. This modulator frequency modulates an oscillator to *increase* its frequency, and has the dual purpose of driving another 6CL6 reactance tube modulator which frequency modulates another oscillator to *decrease* its frequency. These oscillators (½-6BQ7A each) have center frequencies of 20 megacycles and 21.3 megacycles, respectively. These signals are then sent to a 6BA7 mixer tube where the difference of 1.3 megacycles is amplified and sent through a low-pass filter to a cathode follower (½-12AU7). The output of the modulator, which includes a frequency spectrum from 0.3 megacycles to 2.3 megacycles with the carrier frequency at 1.3 megacycles, is fed to a two stage amplifier and thence to a power amplifier head driver (2-6CL6's in parallel), Figure 15. The FM signal is then recorded on the magnetic tape.

The signal on the tape is picked up on the playback head and fed to a cascode amplifier, Figure 16. The first part of the cascode amplifier (½-CK602 tube) is located near the playback head and the second part (½-5670 tube) is located on the playback-amplifier chassis. In addition, the playback-amplifier unit contains three 6AH6 and one 6CL6 amplifier tubes which amplify the signals to a level suitable for feeding the demodulators.

The demodulator unit, Figure 17, consists of a three stage bandpass amplifier (3-6AH6's) with symmetrical clipping to feed a 6C4 phase splitter. The outputs of the phase splitter provide push-pull information for the first grids of the two 6AS6 doubly balanced modulator tubes. At the same time, a 6CL6 oscillator, Figure 18, generates an 11.25 megacycle signal which is amplified by a 6CL6 oscillator driver, Figure 19. The driver is coupled to a bifilar transformer which feeds a push-pull 11.25 megacycle signal to the third grids of the 6AS6 double balanced modulators. Although the conduction angle of the third grids is small, the 11.25 megacycle signal is not doubled in frequency to 22.5 megacycles, as in a push-pull doubler, since the conduction angle is accurately controlled to reduce the second harmonic content in the plate current of each tube to zero. In order to obtain a good 22.5 megacycle null, a condition necessary to minimize the interfering beat signals in the detector output, a critical adjustment of the drive, d-c bias, and grid resistors are necessary. When these tubes are unbalanced by the 1.3 megacycle signal, sum and difference frequencies of the signal and the



All channels are identical to Channel #1

Figure 13. Video Recorder Block Diagram

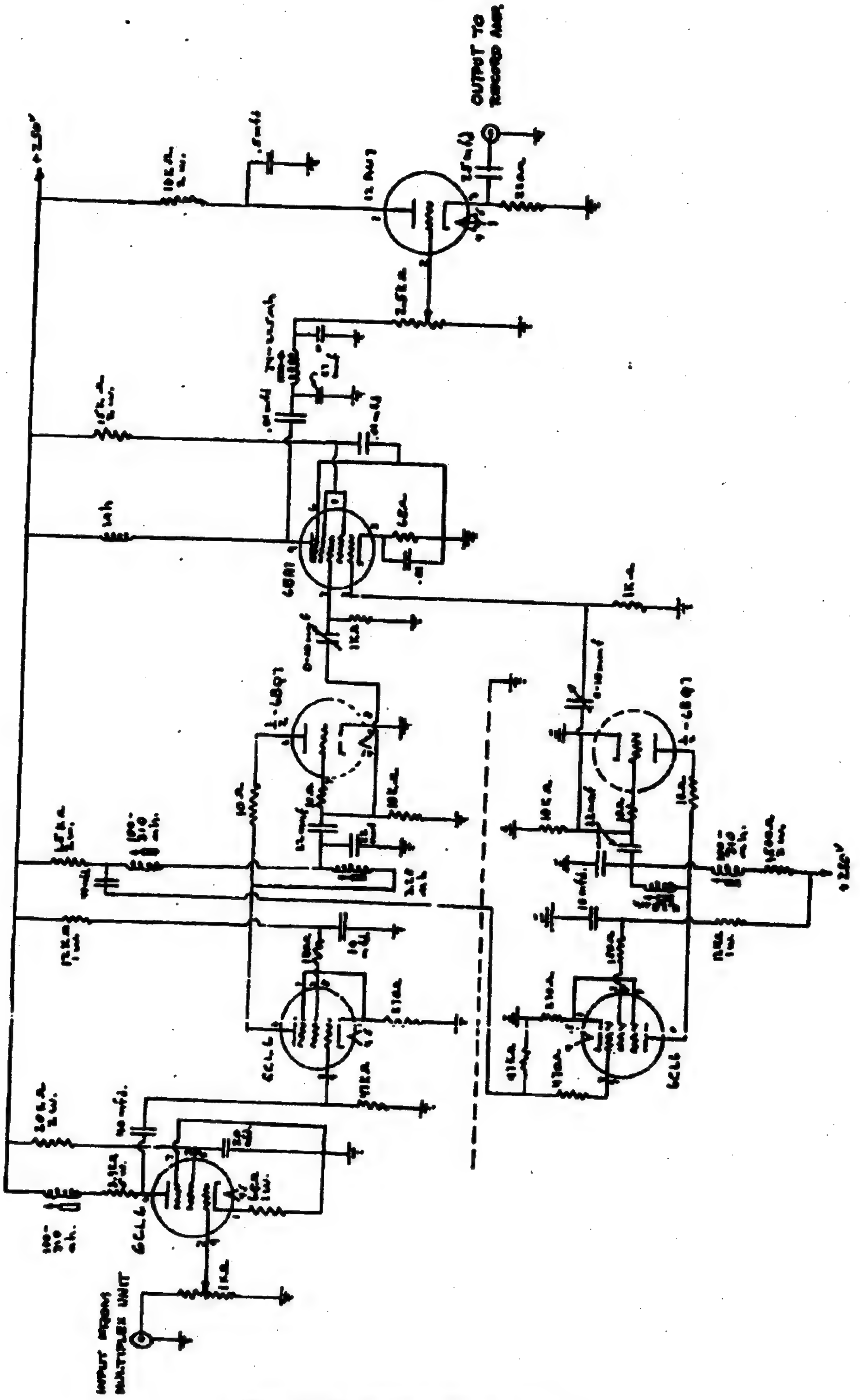


Figure 14. FM Modulator, Schematic Diagram

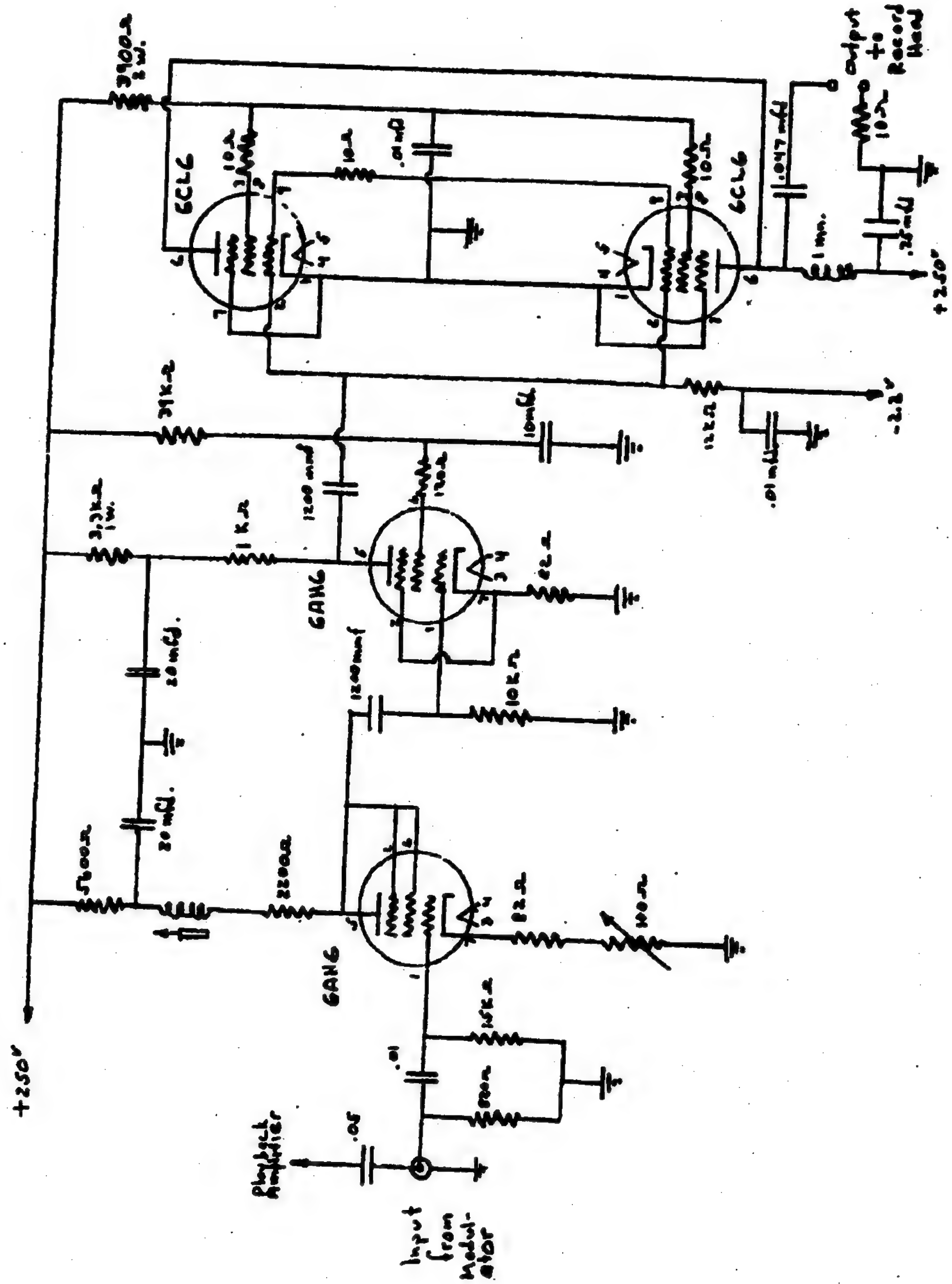


Figure 15. Record Amplifiers, Schematic Diagram

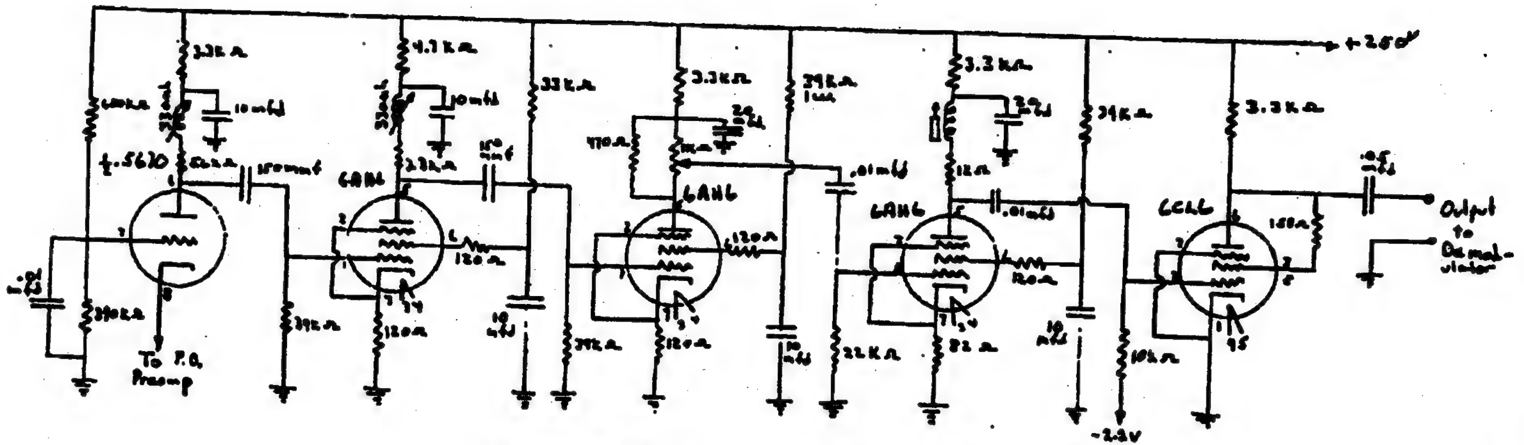
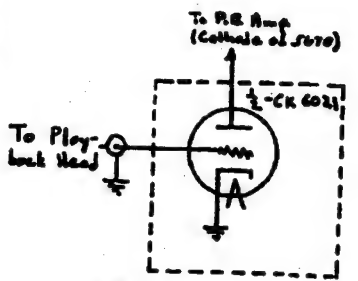
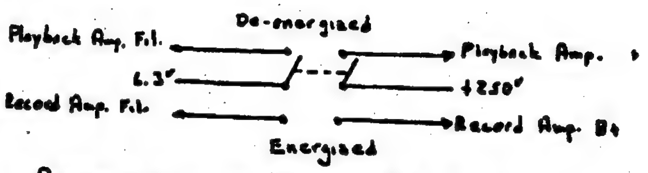


FIGURE 16 PLAYBACK AMPLIFIER



PLAYBACK PREAMPLIFIER



RELAY WIRING ON RECORD - P.B. AMPLIFIER

Figure 16. Playback Amplifier, Schematic Diagram

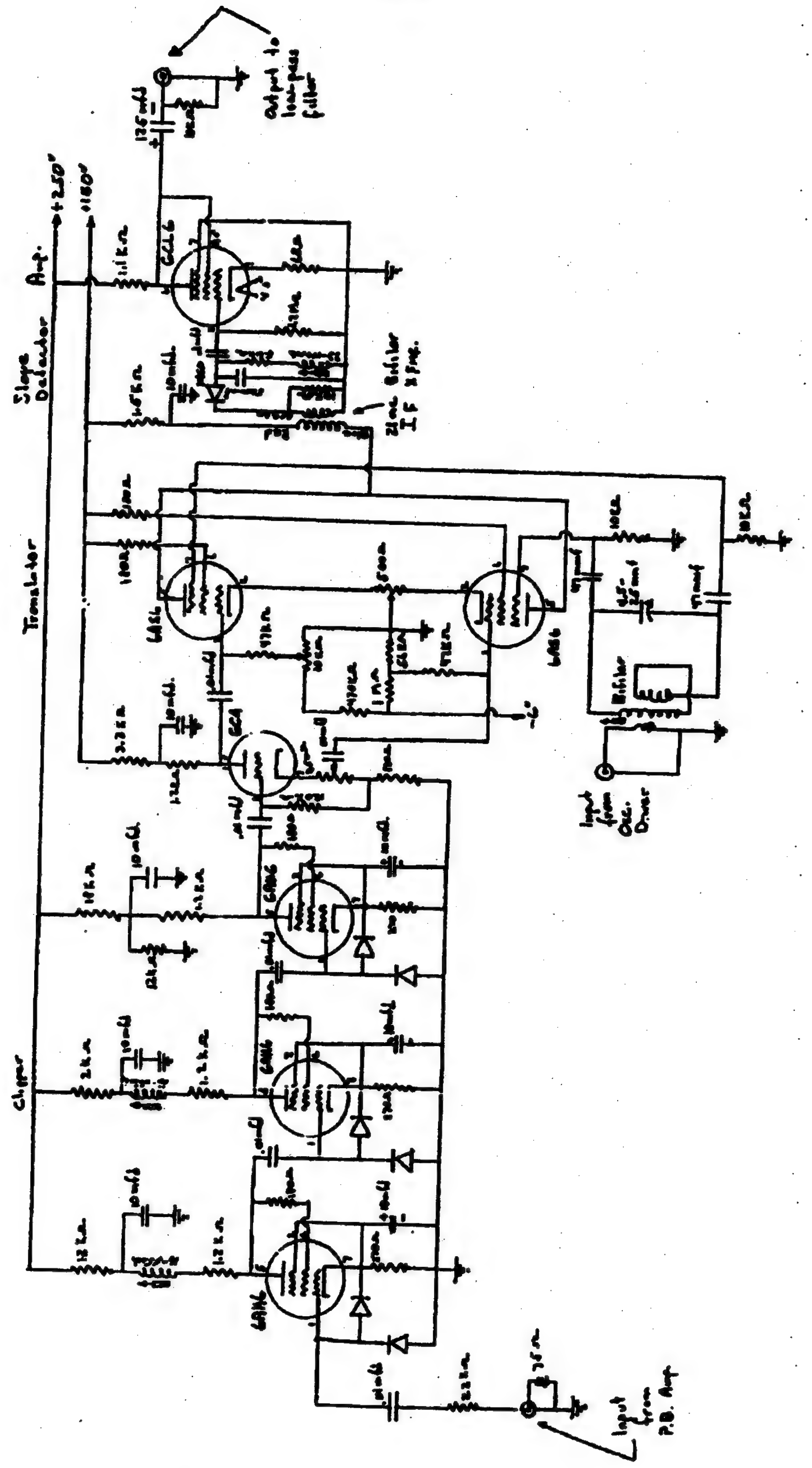


Figure 17. Demodulator, Schematic Diagram

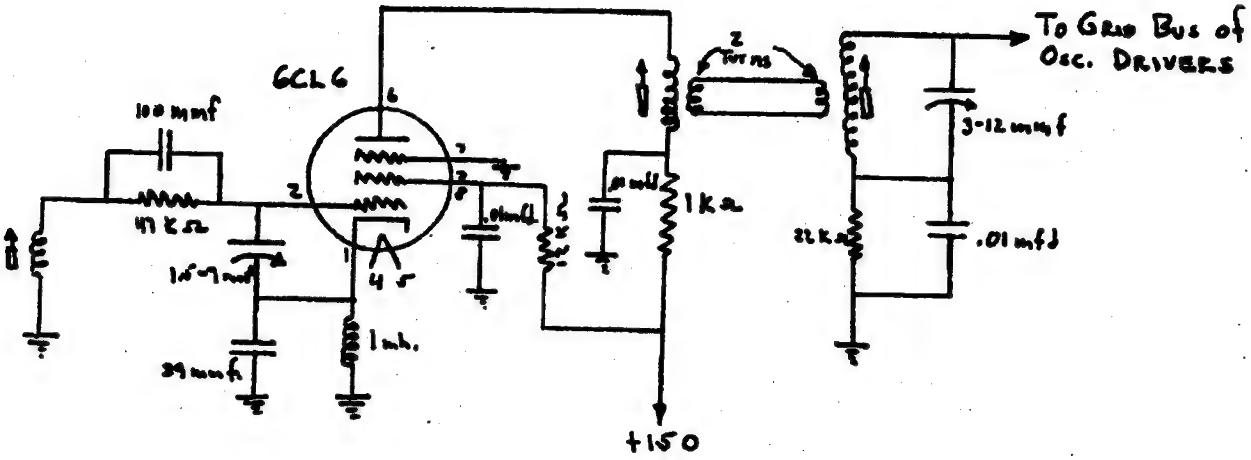


Figure 18. 11.25 Megacycle Oscillator, Schematic Diagram

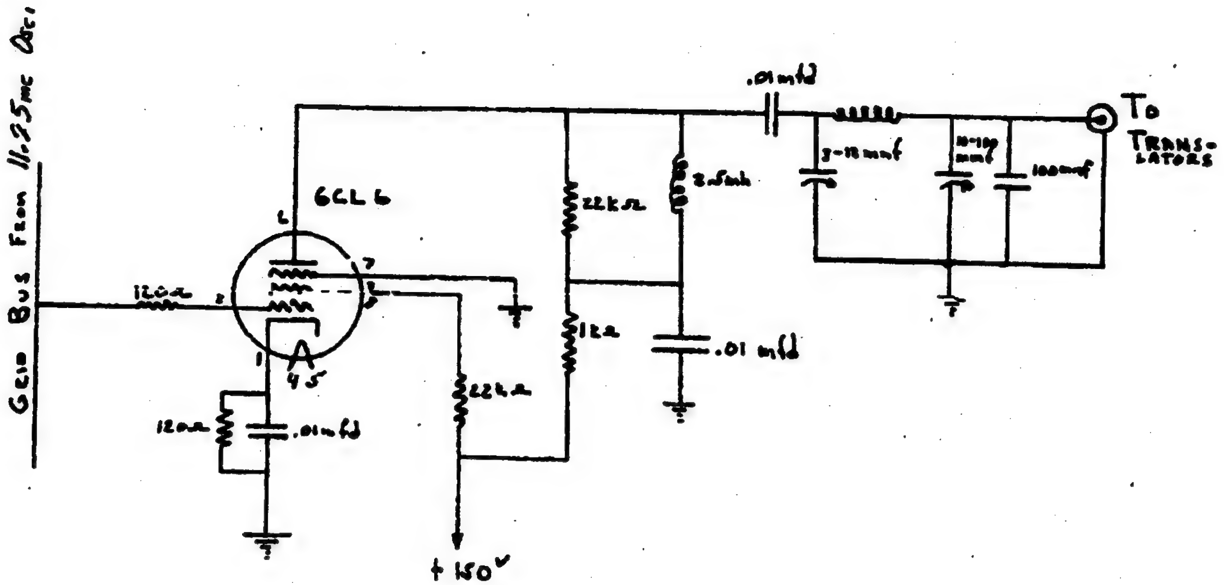


Figure 19. Oscillator Driver. Schematic Diagram

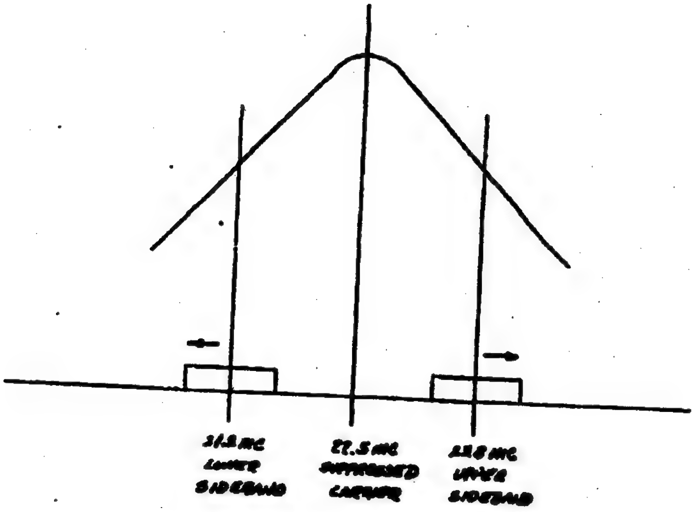


Figure 20. Operation of the Diode Detector

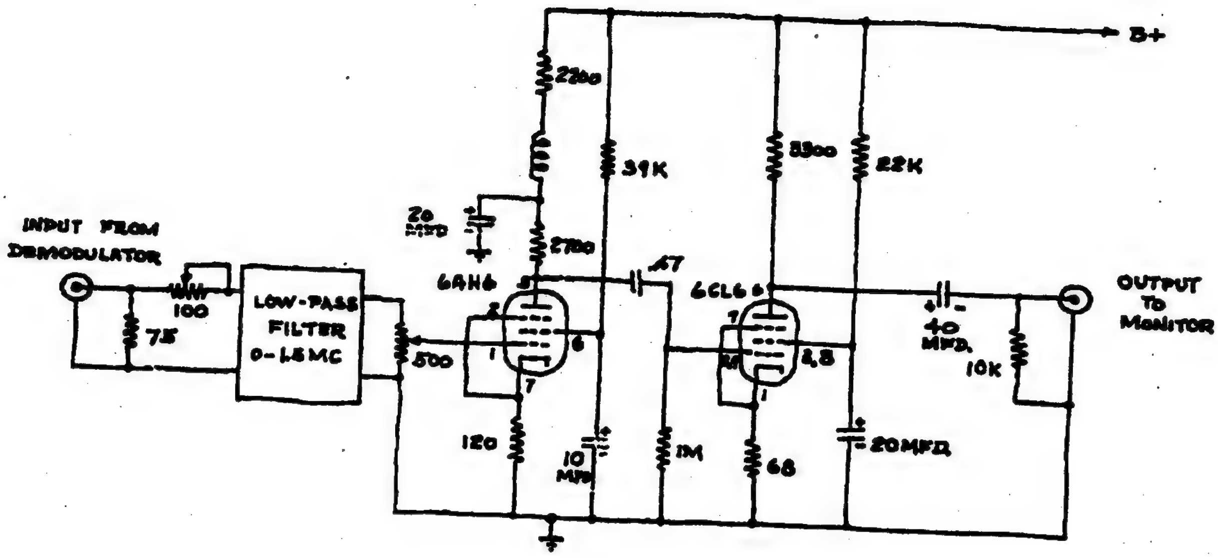


Figure 21. Low-Pass Filter and Amplifier

oscillator second harmonic, 21.2 megacycles and 23.8 megacycles, appear in the plate circuit. These plate signals are transformer coupled to a germanium diode (IN60) where they are rectified to form the video information signal.

The transformer and diode act as a double slope detector as indicated in Figure 20. The signal fed to the diode consists of two sidebands of equal amplitude and symmetrically disposed around the peak of the response curve of the tuned transformer. As the modulating frequency gets larger, both side frequencies fall farther down on the transformer response curve. As the modulating frequency gets smaller, the side frequencies climb up the transformer response curve. Thus, both side frequencies increase or decrease in amplitude together so that they can be added to drive the diode detector. The primary advantage of the double-slope detector is that frequency translation from the low tape frequency to 21 megacycles need not be accompanied by a sharp cutoff filter to eliminate one of the side bands as would be required if the usual single-slope detector were to be employed.

The detected signal is amplified, passed through a low-pass filter and amplifier, Figure 21, and sent through the output multiplex unit where the complete video signal is reconstituted from the signals on the five tape channels.

It will be recalled from elementary frequency modulation theory that an accurate reproduction of the modulating waveform of an FM signal requires the transmission of both sidebands. For this reason high-quality recording of video signals should require a bandwidth of at least twice the highest video frequency, and possibly more, depending on the index of modulation. On this basis, a tape channel of two-megacycles bandwidth could support an FM signal derived from a one-megacycle modulating signal if a small modulation index is used so that only first order sidebands are significant. Although the use of higher frequency-modulating signals in such a system would result in sidebands outside the pass band of the channel, such use would be desirable from the viewpoint of increasing channel capacity. In order to evaluate the deleterious effects of the high frequency cutoff of the tape recording channels on wideband signals, experiments were performed with the transmission of video by FM techniques through limited bandwidth systems.

It has been determined that the transmission of video by FM techniques through a channel of limited bandwidth can result in serious distortion and a great increase in the noise level if the carrier is deviated past the limits of the passband. If, however, the deviation of the carrier is kept within the passband, the great increase in noise does not occur and the distortion is limited. If, in addition, the carrier is placed near the upper end of the pass band, but low enough so that the deviated carrier does not exceed the pass band, it is found that modulating signals which deviate the carrier to lower frequencies are distorted much less than those which deviate the carrier to higher frequencies. This fact can be used to advantage when the modulation signal is a composite television video and synchronizing signal. It is generally recognized that distortion of the video signal will cause less deterioration of a television picture than a similar distortion of the synchronizing signal. It has been verified experimentally that the transmission of video information by an FM signal through a theoretically inadequate channel can result in rather good picture reproduction if the modulation is such as to preserve the synchronizing signal waveform. In this way "single sideband" transmission of FM signals is accomplished and the channel capacity is effectively increased. Thus, the use of FM for recording does not necessarily limit the video modulation to a bandwidth of half the tape channel capacity. Experimental equipments have been constructed on other projects in which a video modulation bandwidth of 5.0 megacycles has been recorded by FM means on a tape channel with a bandwidth of 5.5 megacycles, giving a bandwidth utilization factor of 91 percent.

3. Improvements in Tape Handling

When the development recorder was first completed, tape tension was adjusted to four ounces, as this seemed to be the maximum tension that could be used for a satisfactory wind of the magnetic tape. At first, single flange reels were used on the developmental recorder; however, occasionally the tape would slip off over the edge of the roll. Top flanges of lucite were added in an attempt to prevent this. Lucite was used to permit observation of the tape without the use of holes or spokes in the flange. The use of these two flange reels has been entirely satisfactory during several months of operation with both 1.0 and 0.5 mil Mylar base tape.

In comparing magnetic head performance on the developmental recorder and the loop machine, a given head always performed much better on the loop machine. As an example, head 6TF;A_0^{-4} resulted in 40 db signal-to-noise ratio at two megacycles and a speed of 400 ips on the loop machine but no measurable signal on the recorder at the same frequency and tape speed. The most significant difference in the operating conditions was the 4-ounce tape tension in the recorder and 16-ounce tension in the loop machine. It appeared that the tape tension in the recorder was insufficient to prevent the formation of an air film between the magnetic head and tape at 400 ips. The tape tension was increased to the maximum of eight ounces that could be attained with the reel motors installed in the development recorder. At this tape tension the two-megacycles head output was 10 db less on the recorder than on the loop machine. It was noted that tape wind was entirely satisfactory at eight ounces tape tension, although earlier this high tape tension was not satisfactory. This apparent contradiction is explained by the fact that two-flange reels were now being used where formerly single-flange reels were used.

It was apparent that even higher tape tension would be required to obtain as good performance from the magnetic heads on the recorder as was being obtained on the loop machine. Larger reel motors were installed on the recorder, and at the same time the capstan speed was changed to increase the tape speed from 400 to 500 ips. The tape speed was increased to accommodate the increase in the top frequency in the FM spectrum from the FM modulators resulting from recent changes in the multiplexing system. With the larger reel motors a tape tension of sixteen ounces is obtainable and the head performance is as good on the developmental recorder as on the loop machine.

At the time when the developmental recorder was adjusted for eight ounces tape tension, tape skew measurements were made by recording a two-megacycle signal on each of the six tracks, and then during playback various combinations of pairs of tracks were added together and viewed on an oscilloscope. Tape skew would result in relative time displacement of the signals from two tracks and appear as a heavily amplitude-modulated signal. It was estimated that the relative time displacement resulting from skew was about one microsecond. This means that multiplex information from the various tracks would not add up properly. The time periods of this amplitude modulation indicated that wobble of the top flange of the tape reel was introducing the tape skew. It appeared that very precise tape reels would be required to minimize this source of tape skew. Before attempts were made to construct very precise reels the tape tension was first increased to sixteen ounces, and then it was found that the time period of these amplitude variations matched that of the rotary stabilizer and not the tape reels.

The original mechanical design of the development recorder included an air-bearing rotary stabilizer in the tape path. The span of tape between this stabilizer and the capstan was about 5 inches, and the point of magnetic head contact was about the middle of this span. This type of stabilizer had been found to be quite useful for reducing flutter on some previous wide-band magnetic-tape equipment. Although measurements of eccentricity and wobble of the stabilizer did not reveal sufficient magnitudes of any deviation to account for the degree of tape skew encountered there could be no doubt that the problem was serious since it did not permit the multiplexed information in the several tracks across the width of the tape to be added up properly.

It was decided to replace the rotary stabilizer with a non-rotating air tape guide. This is the same size and in the same position as the rotary stabilizer; it is, in fact, very similar to the stabilizer pulley except that it does not rotate and the tape contacting area has grooves which are supplied with air under moderate pressures of around two to five psi. It was then found that tape skew was very low provided that the distance between the flanges of the edge guides was no more than about one mil more than the width of the tape. A number of samples of tape were checked for tape width throughout their length. Table 1 shows the results of measurements at several points along the entire length of two 3500 foot rolls of magnetic tape.

Table 1
Results of measurements of tape widths

Sample No. 1	*Sample No. 2*
0.4976 inch	0.4967 inch
0.4974	0.4967
0.4971	0.4963
0.4974	0.4962
0.4974	0.4965
0.4971	0.4969
0.4973	0.4968
0.4976	
0.4972	

The experience of other groups within RCA indicates that 0.5-inch wide tape could be obtained in large quantities with a definite width maintained within 2 or possibly 1 mil throughout any roll and from roll to roll over a period of years.

Using tape sample No. 1 with the tape guide set for 0.4980 inch it was found that the signals from any two tracks would always add in phase. It was estimated that the maximum time displacement error between tracks was about 0.02 microsecond. This is more than adequate to meet the time delay error requirements of a high quality video system.

This is very significant information relating to multiplexing wide band video on several parallel magnetic tracks. This freedom from excessive tape skew is one of the important factors which makes a multiplex magnetic video recorder feasible.

4. Reduction in Head Circuit Crosstalk

The manner in which the six-channel head circuits had originally been wired and cabled resulted in excessive inter-channel crosstalk, about 20 db. An inspection of the layout suggested that the crosstalk resulted from inductive, capacitive and ground loop coupling in the head cabling. The magnetic head itself had been measured to have a crosstalk factor of around 45 db. When the FM recording system was first being considered it was assumed that the capture effect in FM detection would make crosstalk between tape tracks unimportant. Measurements indicated that 20 db of crosstalk of the FM signal between channels resulted in an interference signal about 20 db below the desired signal after FM detection. An analysis of this situation indicates that this should be the case and there is no reason to expect any capture effect. If the channel 1 carrier frequency is 1.30 megacycles and there is 20 db crosstalk of the 1.31 megacycle carrier channel in 2, the 13.1 megacycle crosstalk signal will act as an FM sideband with respect to the channel 1 carrier. After limiting and FM detection the crosstalk will appear as a 10-kilocycle signal on the output of the system. This was the case in actual practice and pronounced bar patterns were observed when all six channels were recorded simultaneously with either the same or different video signals on each channel.

The wiring and cabling of the head circuits, including the pre-amplifier unit mounted close to the head, were changed to minimize all forms of coupling. The crosstalk was then about 40 db and all six tape channels could be used without any interference between channels.

5. Magnetic Tape Evaluation

During the several months covered by this report practically continuous evaluation tests were conducted on Reeves-Soundcraft and Minnesota Mining magnetic tapes. During the early part of the period only Reeves tapes could be used at all, as has been the case for about two years. Although Minnesota Mining tapes have been consistently better with respect to amplitude variations, they were completely unsatisfactory with respect to head rub-off at tape speeds around 500 ips. Toward the end of the period Minnesota Mining began supplying tapes which could be used at 500 ips. Two 3500-foot samples were evaluated and found to have not even one complete drop-out. However, when these two lengths were spliced together a number of drop-outs were encountered in the region of the splice. Visual inspection revealed surface blemishes which could result in drop-outs. Approximately 100 feet containing these blemishes were removed and the remaining tape spliced together. The resulting 6900-foot length of tape with one splice did not have any drop-outs sufficient to produce a visible defect using the FM recording system. After this tape had been used for approximately 100 passes a few drop-outs became apparent. Visual inspection of the tape revealed small bits of tape coating material on the base side of the tape which deformed the magnetic coating enough to produce a drop-out. This is a result of the fairly soft coating that Minnesota Mining uses, even on their video recording tapes. In contrast the Reeves-Soundcraft tape that was developed for high speed applications does not exhibit this effect at all and appears to have a useful life of tens of thousands of passes. Unfortunately no Reeves tape that we have tested has equaled the freedom from drop-outs and amplitude variations that is characteristic of nearly every sample of Minnesota Mining instrumentation or video tape that has been tested.

6. Multiplexing Systems

a. FREQUENCY MULTIPLEXING

At the beginning of the project it was proposed that a frequency-division multiplexing system be used to put wideband video information on a plurality of tape channels. It was further proposed that conventional bandpass filters be employed for this use since the resulting phase distortion could be corrected by reverse playback. When the point in the development was reached where the information in one frequency-division band was added to the adjacent band an inherent limitation of the reverse playback scheme became apparent. The information in the two bands did not add up properly but there was no straightforward way of determining why. In a reverse playback system no part of the system can be evaluated for the manner in which it will perform in the overall system unless the whole system is working. Any test that is made must invoke reverse playback and little can be done to circumvent this limitation.

Because of this time consuming difficulty the use of reverse playback for phase correction was abandoned.

An effort was made to develop a set of bandpass filters that coud be used in a frequency-division system without dependence upon reverse playback as mentioned above. Although this goal has often been considered unattainable, it was hoped that some recent developments might offer new possibility. In the course of consulting with filter experts within RCA it was brought out that a system of deriving a series of related bandpass filters from one multiple tapped delay line is ideally suited for this application. Such a system of filters derived from a wide-band constant-phase-shift delay line inherently has ideal crossover characteristics and, if made correctly, rather complete freedom from phase distortion. A filter of this type suitable for this application was designed and constructed. Unfortunately the basic delay line was inadequate and there was insufficient time to construct another delay line. It is our belief that this approach is feasible and is perhaps the only system now known which will provide frequency-division multiplexing without reliance on reverse playback.

b. TIME MULTIPLEXING

A time-division multiplexing system that was available from another RCA activity was integrated into the six-channel tape system for an evaluation in this application. A color TV broadcast signal was recorded by this system and the reproduction of the recording, while not of commercial quality, was good enough to prove that the color information could be reproduced. It was determined that the picture quality was being limited by mechanical vibration in the development recorder. The capstan is known to rotate at a very constant speed. However, the magnetic head is mounted on the top panel of the recorder and those vibrational components of the panel which are rotary and centered on the capstan axis result directly in apparent tape-speed variations. Such variations could be detected in the capstan servo. These speed variations resulted in time jitter beyond the accommodation of the time-division system and were not overcome in our experiments. The mechanical vibration arises when high tape speeds, of around 400 or 500 inches per second, are used. A previous recorder built on the same general pattern for another RCA activity, but operating at 100 inches per second, did not exhibit this limitation as a result of mechanical vibration. By the time this difficulty was noted there was insufficient time to make necessary corrections and a completely satisfactory recording was not attained.

c. OTHER MULTIPLEXING CONSIDERATIONS

The television magnetic-recording system which has been considered under this contract employs what might be called optical time division multiplex to permit one camera to look at 36 different side by side images of the ground. Under the proposed specifications this resulted in a camera video signal of eight megacycles. Electrical multiplexing was proposed for narrowing the bandwidth so that these signals could be recorded on and played back from tape. Thus, optical multiplexing was used to increase the information rate on an electrical channel to the extent that electrical multiplexing was required to narrow the bandwidth to put the information into useable tape recorder form.

The complex signal processing system mentioned above resulted from the proposed use of only one TV camera. This proposal was made because of the size, weight, and performance of television cameras existing at the time of the initiation of the contract. Before the magnitude of the difficulties of recording multiplexed video was realized, it was believed that the use of multiplexing was in fact the best way to proceed. Two occurrences have altered our thinking. The first is that high-quality miniature television cameras are now available using vidicons and transistors, which give performance of the degree required for reconnaissance work and which are so small, light in weight, and economical of power consumption that several could be used in the place of one image orithicon camera. The second is our negative result with regard to the use of time or frequency-division multiplex for eight-megacycle video recordings.

Another approach to the problem which should be given careful consideration when further television reconnaissance work is to be undertaken is the use of optical multiplexing only to the extent that the output of one camera may be recorded on magnetic tape with its full bandwidth. If, for example, 36 cameras were used, each to look at just one image, and 36 tracks were used on the tape, the recorded signal on each channel could be one thirty-sixth of 8 megacycles or 222 kilocycles. The recording of such a signal could be handled with little difficulty. One need not go to this extreme, however, to realize an advantage. If, for instance, six cameras were used, each optically multiplexed to look at six images, and the output of each recorded on one of six tracks, the recorded bandwidth would be roughly 1.3 megacycles on each channel. A capability for this type recording has been shown by the studies reported here.

A more detailed discussion of this parallel channel system is given on pages 3-22 through 3-26 of the Advanced Reconnaissance System, Final Engineering Report, June 30, 1956 (Contract AF33(616)3104). In this reference a simplified parallel channel system using four vidicons illustrates the basic concept of this approach. Detailed information is given on weight and power requirements of such a system.

It should be noted that regardless of the system of recording chosen, techniques are available for assembling the information into one electrical channel for transmission to the ground. These techniques were not considered as a part of this section of the study.

7. Conclusions

Our investigation of recording wideband video information on magnetic tape has resulted in the development of many improved techniques for magnetic recording which are important for many applications of magnetic recording. It has been demonstrated that tape transport mechanisms can be built in which tape can be run at 500 inches per second with the capstan speed controlled to an accuracy of one part in 250,000 when the capstan speed is compared with a crystal oscillator. Magnetic heads have been constructed which will permit the recording and playback of information at frequencies in excess of 2.5 megacycles at a signal-to-noise ratio of 40db with the above mentioned tape mechanism. Multitrack heads with six channels on one-half inch tape have exhibited better than 45db adjacent channel crosstalk. Frequency modulation has been used for recording information on tape to provide a video bandwidth of 2.5 kilocycles per inch per second tape speed. It is estimated that the life of magnetic heads in this application is about 1,000 hours and that a given length of tape will be useable for at least 10,000 and possibly 100,000 passes over the head with no loss in picture quality, provided a tape lubricant is employed.

Back-to-back multiplexing, i.e. encoders feeding decoders directly without using the tape channels, has been made to work successfully for the time-division system, and for the frequency-division system to a lesser extent. In both cases, the introduction of the tape channels has brought on added difficulties which were not overcome in our experimental work. It is believed, however, that further work could result in a successful system using either type of multiplexing. The difficulties are such, however, as to make this general method of recording video information rather unattractive at the present time. Our conclusions in this regard are strengthened by the recent success of the rotating-head-wheel system for video magnetic recording in which heads scan transversely across the tape. This type of equipment resulted in a successful demonstration of the recording of monochrome television pictures in the spring of 1956 by the Ampex Corporation and of color television pictures in the fall of 1957 by Commercial Electronic Products, RCA. The high quality of these recordings when compared with the results of our multiplexed recordings, indicates that further development should proceed along the line of transverse recording. The use of a rotating head wheel is considered to be a serious disadvantage, however. It is hoped that developments in the near future will result in a transverse scanning head using no moving parts. The development of such a device would most certainly pave the way for the use of transversely scanned recording for television-reconnaissance applications.

C. KINESCOPE RECORDING

1. Introduction

In the report for August 1, 1956, it was noted that the first sample of the new triode-gun magnetic-focus kinescope was not significantly better than our best pentode electrostatic tubes as to resolution.

A second sample kinescope of the triode-gun magnetic-focus type was tested by Dr. O. H. Schade, who found it not up to his expectations. This tube was given a similar series of tests in RCA-Camden—pertinent data is shown later in the report.

Concluding the evaluation program, two development tubes were studied and the test data compared with that of the tube referred to in the preceding paragraph. The percent kinescope response was not as favorable as that of the reference tube.

As a result of these tests it is believed that light scattering and "image spread" in the phosphor, of a five-inch tube, are limiting the rendition of fine detail (500 to 600 TV lines) as much as is the distribution in the beam spot itself. Rather good previous evidence indicates that the improved P16 phosphor was considerably better in this respect than the P11 (which is widely used for kinescope photography). However, it now appears that a ten-inch P16 tube may be required to get a 560 TV-line response of around 75 percent or better, as measured on the phosphor. Fortunately, the special Eastman U.V. lens will work about equally well at this image-to-object ratio.

Another encouraging possibility is the development of a radically-new transparent and thin phosphor by the RCA Tube Department. It is expected that this may produce satisfactory results in even the five-inch tube.

2. Outline of Procedure Used to Evaluate Kinescopes

For evaluation of these experimental triode-gun magnetic-focus kinescopes, a monochrome recording chain was revised. A large diameter precision deflection yoke was put into operation with sufficient power for full image deflection. A precision focus coil was also installed giving what was considered to be the best magnetic focus that could be devised for triode-gun kinescopes.

The 3 tubes under test were as follows:

1. Kinescope PP 1354-3 Long-Triode 5-inch, P16 phosphor—this tube had been previously evaluated by Dr. O. H. Schade and used in this report as a reference tube.
2. Kinescope PP 1507-1 Long-Triode 5-inch, P16 phosphor.
3. Kinescope PP 1508-1 Short-Triode 5-inch, P16 phosphor.

The monochrome recording unit was equipped with a photographic camera having a 30-inch bellows and a Kodak Kinescope Ektar lens 4:5-1, 75 mm, f/2.3 ultraviolet, mounted in reverse to permit a magnification of about 10.7:1 from kinescope to film. For all data taken, the lens was set at f/4. Exposures were for five seconds.

A sine-wave signal generator was used and frequencies of .6, 2, 4, 5½ and 7 megacycles were exposed on Ansco Triopan film, from the kinescopes adjusted as follows:

1. For each kinescope, the grid bias was found which would give a density on film of approximately 1.6. This bias was recorded as hi-lite level for that particular tube.
2. Similarly, for each tube, the bias was adjusted to give a dim scanning line image on film (within the density range of about 0.2 to 0.6). This bias was recorded as hi-lite level for that particular tube.
3. Blanking bias was also recorded.
4. For each tube, the d-c bias and the amplitude of the sinusoidal test signal at 0.6 megacycle (representing relatively coarse picture detail) were adjusted so that the signal excursions corresponded to the hi-lite and lo-lite bias values. A film exposure was then made with this 0.6-megacycle signal.
5. The frequency was then changed successively to 2, 4, 5.5 and 7 megacycles, and exposures made, keeping the signal excursions on the grid at the same values as for 0.6 megacycle. An attempt was also made to keep the d-c bias component constant. Although this was not fully achieved, it is believed that the d-c bias shifts which occurred did not alter the results appreciably since the kinescopes have a reasonably constant "gamma" over the range used.

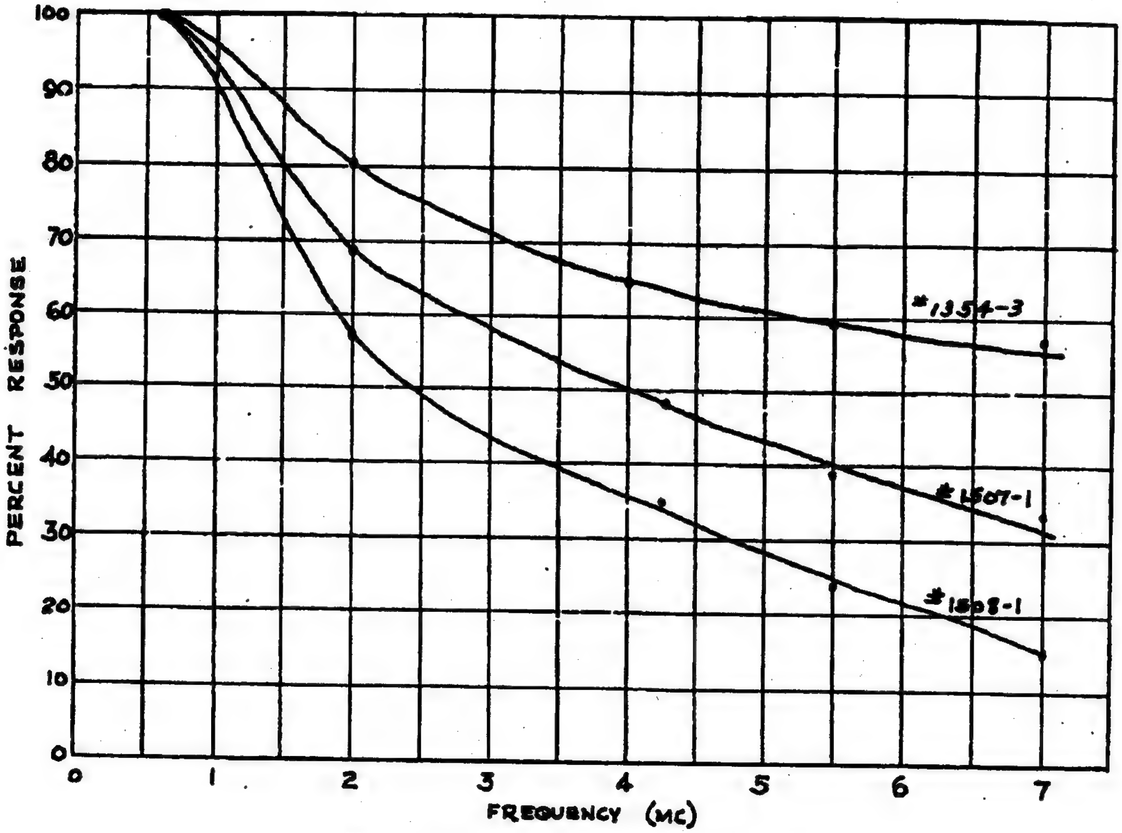


Figure 22. Kinescope Response Curves for Three Types of Kinescopes

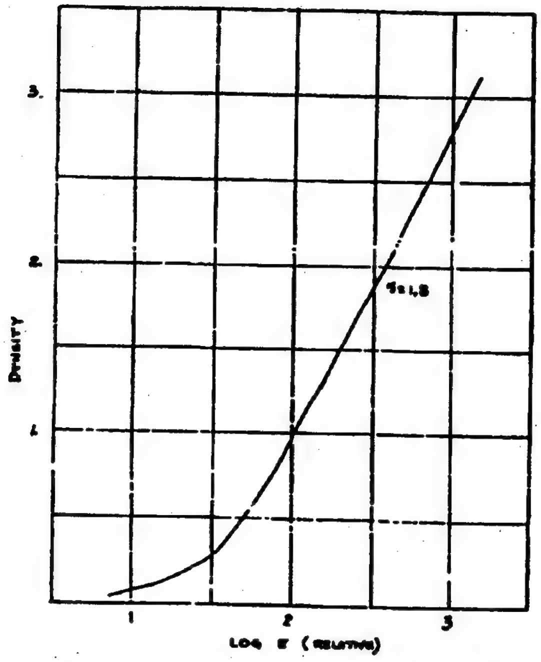


Figure 23 Sensitometric Curve for Ansco Trisopan Dev. 3 Minutes, D-16

The data for each kinescope, from which the kinescope response curves given in Figure 22 were obtained, are given below:

Kinescope No. PP 1354-3
(Reference Kinescope)

Frequency of Sine Waves	*0.6 mc*	*2 mc*	*4 mc*	*5.5 mc*	*7 mc*
Lo-Lites (Film Density)	.22	.245	.245	.2	.06
Hi-Lites (Film Density)	1.66	1.54	1.46	1.15	.5
Log E Hi-Lites (from film Sensitometric Curve, Figure 23)	2.36	2.28	2.25	2.08	1.72
Log E Lo-Lites (from film Sensitometric Curve, Figure 23)	1.45	1.47	1.56	1.4	1.05
Log E Difference [Log E Hi-Lite–Log E Lo-Lite]	.91	.81	.69	.68	.67
Exposure Ratio (Antilog of Log E Difference)	8.1	6.45	4.9	4.77	4.67
Percent Kinescope Response (derived from exposure ratio taking ratio at 0.6 mc as 100%)	100	80	60.5	59	58

Kinescope No. PP 1507-1
(Long Gun)

Frequency of Sine Waves	*0.6 mc*	*2 mc*	*4 mc*	*5.5 mc*	*7 mc*
Lo-Lites (Film Density)	.61	.88	1.06	1.23	1.62
Hi-Lites (Film Density)	1.79	1.77	1.67	1.64	1.87
Log E Hi-Lites (from film Sensitometric Curve, Figure 23)	2.45	2.42	2.37	2.35	2.5
Log E Lo-Lites (from film Sensitometric Curve, Figure 23)	1.8	1.94	2.04	2.12	2.32
Log E Difference [Log E Hi-Lite–Log E Lo-Lite]	.65	.48	.33	.23	.18
Exposure Ratio (Antilog of Log E Difference)	4.46	3.02	2.14	1.629	1.51
Percent Kinescope Response (derived from exposure ratio taking ratio at 0.6 mc as 100%)	100	67.7	48.	37.8	33.8

Kinescope No. PP 1508-1
(Short Gun)

Frequency of Sine Waves	*0.6 mc*	*2 mc*	*4 mc*	*5.5 mc*	*7 mc*
Lo-Lites (Film Density)	.16	.23	.47	.67	.8
Hi-Lites (Film Density)	1.65	1.4	1.38	1.42	.98
Log E Hi-Lites (from film Sensitometric Curve, Figure 23)	2.35	2.22	2.2	2.22	2.06
Log E Lo-Lites (from film Sensitometric Curve, Figure 23)	1.35	1.47	1.66	1.85	1.95
Log E Difference [Log E Hi-Lite–Log E Lo-Lite]	1.00	.75	.54	.37	.05
Exposure Ratio (Antilog of Log E Difference)	10.0	5.6	3.48	2.34	1.12
Percent Kinescope Response (derived from exposure ratio taking ratio at 0.6 mc as 100%)	100	56	34.8	23.4	11.2*

* Converted to 15 because of signal fall-off at this frequency.

Tubes 1354-3 and 1507-1 each had the same anode structure (4-inch long tube, and 18-inch limiting aperture), and all tubes had support rods of "multiform" glass. Tube 1354-3 had a G2 ring (primarily a corona device), which the later two did not have, and its G1 was a stamped unit with special aperture-edge beveling and plating treatment. Tube 1507-1 had a precision-machined G1, of slightly smaller aperture. Tube 1508-1 had a thinly coined and drilled G1 structure, with the same aperture diameter as 1507-1, but its anode was 2 inches long with a somewhat smaller limiting aperture than the other two.

Some measurements of response were also made in the picture corners, but these turned out to be more an evaluation of the focus modulator (dynamic focus) device than of tube and deflection performance in the corners. The dynamic focus was not fully adequate, but its performance can be made satisfactory. When the main focus control was reset for optimum in a given extreme corner, the 560 TV-line response was generally in the order of ⅔ as good as at the center.

It should be noted that, in May 1957, a development project started in the RCA Tube Department which is expected to result in a significant improvement in resolution and fine-detail contrast for the type of kinescopes considered for this application. It is expected that there should be very little decrease in response around 200 TV-lines and, even on a 5-inch tube, the 560 TV-line response in the central area of the phosphor should be significantly better than that shown in the accompanying data.

The major change in kinescopes is the probable use of a transparent phosphor, instead of a "translucent" one. This should greatly reduce the image deteriorations due to light scattering in the present comparatively-thick granular structure, and the flare and halo caused by ambient light and reflections from the front of the face plate.

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